

# **The 16th International Symposium on Wearable Computers**

**ISWC 2012**

**Adjunct Proceedings**



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**Adjunct Proceedings**

Newcastle Upon Tyne, UK on June 18-22.

Adjunct Proceedings of the 16th International Symposium on Wearable Computers (ISWC 2012)

Newcastle Upon Tyne, UK on June 18-22.

Oliver Amft, Christian Bürgy, Lucy Dunne, Mark van Gils, Kai Kunze, Martin Kusserow, Jane McCann, Juha Pärkkä, and Clint Zeagler (eds.)

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# Welcome message from the General Chair



Oliver Amft,  
TU Eindhoven, NL

A cordial welcome to ISWC 2012 – the 16th International Symposium on Wearable Computing, held between June 18 to 22 in Newcastle Upon Tyne, UK. ISWC is known as the premier venue for presenting pioneering work and advancements in on-body, wearable, and mobile technologies. Moreover, ISWC is known to bring together researchers, product vendors, fashion designers, textile manufacturers, users, and related professionals with the joint goal to push the limits of technology and methods.

Over the years, the ISWC series has developed a set of good traditions, which we aimed to foster and match with novel developments. Eventually, the hard work of many volunteers resulted in an exciting conference program for 2012: besides paper presentation sessions, ISWC features a Tutorials and Workshop program on the first two conference days. The Doctoral Consortium enables starting PhD candidates to discuss their ideas in a focused forum. During the main conference days, a Panel session, Posters, Videos, and Demos form enriching elements of the ISWC program. We are particularly proud to host a Design Competition, which is freely accessible to the public.

Encouraged by the last year's success, ISWC 2012 is again held jointly with Pervasive 2012. Attendees of both conferences can enjoy hopping between presentation sessions and attend shared program events, such as the keynotes.

The soar of smartphones, unobtrusive sensors, and mobile user interfaces has been part of ISWC's success and recognition over the past years. However, research around novel smart materials for sensing and responding functions is currently making great leaps and may lead into ISWC's future. In the keynote speech of Elias Siores, who is working in the vanguard of this new wave, we will take a close look at the recent advances.

I like to thank all active members of the organising committee, the technical program committee, and all reviewers for their enthusiasm and effort to support the conference organisation. Daniel Ashbrook and Mark Smith spurred innovative technical contributions through the call for papers, managing the paper selection process, and taking care of any issues in the process. Moreover, I am grateful to all track chairs of ISWC 2012, including Tutorials and Workshops, Videos, Demos, the Doctoral Consortium, and the Design Competition, for their effort. Stewart von Itzstein managed the preparation of the IEEE proceedings, Nirmal Patel promoted the conference through different media, and Máté Toth took care of the website. Finally, ISWC 2012 would not have been possible without the great help of Patrick Olivier and his team at Newcastle University, who took excellent care of the local arrangements. We thank the IEEE Computer Society for technically co-sponsoring ISWC 2012, as well as Google and Nokia for their kind donations to support the conference.

Please enjoy the ISWC 2012 program!

Oliver Amft,  
ISWC 2012 General Chair



# Organising Committee

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# **ISWC 2012**

## **Demonstrations**

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# Airwriting: Mobile text-entry by 3d-space handwriting

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## Abstract

*We demonstrate a wearable text-entry system. Users can write text in the air, as if they were writing on an imaginary blackboard. Motion is sensed by inertial sensors attached to the back of the hand. Written text is spotted and recognized by a two-stage approach using SVMs and HMMs. The system works in a person-independent manner and is capable of recognizing text written in block capital letters at natural writing speeds without any pauses.*



**Figure 1. System usage illustration showing the wireless data glove with all components.**

## 1. Demonstration System

This paper describes the demonstration of our airwriting input system introduced in the accompanying paper [2]. Accelerometers and Gyroscopes on the back of the hand measure hand motion and the written text is recognized based on the acquired sensor signals. Other approaches to 3d-space handwriting recognition have been proposed but are restricted to single characters or short single words, since they rely on the estimation of the actual trajectory and therefore suffer from sensor errors accumulating over time [1, 3].

Figure 1 shows our data glove with the inertial measurement unit attached to the back of the hand. The sensor data is sent wirelessly to a laptop where all processing takes place. We use a two-stage approach for spotting and recognizing handwriting. In the first stage, a SVM-based classifier detects signal segments that are likely to contain handwriting. Only those segments are passed on to the second stage, in which the actual text is recognized. In the second stage HMMs are used to model characters and words and a statistical 3-gram language model is used to model the probabilities of certain word sequences. This allows for the recognition of whole sentences. The vocabulary of the recognizer contains more than 8000 words. A user can write arbitrary sentences formed out of the words contained in the vocabulary. We reach an average person-independent word error rate of 11% in a nine user experiment. Users can write in one continuous motion, they do not need to

make any artificial pauses to explicitly mark character or word boundaries. All handwriting must be in block capital letters and should be done in place, i.e. no motion from left to right is necessary. The size of the characters written should be approximately 20 cm in height, but the system usually still gives good results if the height is between 5 cm to 40 cm. Writing speed can vary as well, in our experiment with 9 unexperienced users we observed an average rate of 72 characters per minute, whereas an experienced user reached 110 CPM. The decoder continuously outputs the hypothesis with the most probable sentence given the signals received so far. If the user stops to write for a certain amount of time (approx. 2 s), the spotting stage detects the end of the handwriting motion which leads to the output of the final hypothesis. The system works in an always-on manner, if the user starts writing again, the decoding starts from the beginning.

## References

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- [3] W.-C. Bang, W. Chang, K.-H. Kang, E.-S. Choi, A. Potanin, and D.-Y. Kim. Self-contained spatial input device for wearable computers. *ISWC*, 2003.

# Icebreaker T-shirt: a Wearable Device for Easing Face-to-Face Interaction

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## Abstract

*This paper discusses the development of Icebreaker T-shirt with results from an experiment with shy users.*

## 1. Introduction

Initiating a conversation is a common challenge for shy people; here, we introduce the Icebreaker T-shirt, designed to be worn in real-world social events, and aimed at increasing comfort feeling and familiarity between strangers by leveraging online social network information e.g. Facebook on clothing. Using advances of computer-mediated communication (CMC) with design principles of slow technology that values reflective experience of the user, we examine to what extent advanced technologies can improve social skills and may lead to more meaningful relationships in the real world.

## 2. Background

Various forms of online CMC have been reported to increase social relationships due to the fact that they allow users to focus on information content rather be overly concerned with social customs and non-verbal clues from interaction partners. However, these allow identity distortion, unrealistic expectations, and withdrawal from real-world activities; thus making face-to-face communication harder for socially anxious and low interpersonal skilled users. Our approach has similarities to social proximity applications (SPAs) in smartphones – allowing users with similar interests to share online information. However, most SPAs are deployed in unsophisticated objects causing low aesthetic value in “wear-ability” that can limit the usefulness in sensitive social situations. Also, none so far has been designed to support shy users.

## 3. Design

Developed on a hypothesis that familiarity may

enhance comfort and relaxations when meeting strangers, thus helping the wearer select new acquaintances while maintaining the naturalness of the social interaction and comforting property of clothing. Embedded with a set of Radio Frequency Identification (RFID) reader and tag on the cuff of its long-sleeve, the shirt allows two wearers to exchange identities when shaking hands. Next to the RFID system, there is a microcontroller designed to retrieve their public profile and preference from their Facebook pages via a smartphone (this feature was left out, and information of test subjects was pre-stored in the microcontroller used in the first proof-of-concept prototypes). The microcontroller matches users’ profiles and preferences resulting in a level of their social compatibility displayed using conductive thread and heated-sensitive paints. The more interests they have in common, the higher their compatibility levels (conveyed with more colourful display) become.

## 4. Experiment

Tested with 11 self-report shy subjects in two speed-dating sessions: with shirt and without. 73% said the shirt was helpful to their meeting with strangers. One said: “*It gave a sense of having something in common to begin the conversation, something we both were interested in. Whereas when we didn't have the shirt, I felt we were only trying to make small talk.*” Although, the sample tested was small, our first experiment underlines some problems and potentials of the chosen technologies for improving interpersonal skills of shy people.



Figure 1. Two shirts tested in a dating session

# **ISWC 2012**

## **Videos**

ISWC 2012  
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# H4-TEG: A Huffman Base-4 Text Entry Glove Demonstration

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## Abstract

We designed and evaluated a Huffman base-4 Text Entry Glove (H4-TEG). H4-TEG uses pinches between *the thumb and fingers on the user's right hand*. Characters and commands use base-4 Huffman codes for efficient input.

## 1. Introduction

We describe a one-handed text input technique that makes use of a pinch activated glove called Huffman base-4 Text Entry Glove (H4-TEG). Our goal was to reduce or eliminate the need for visual attention and to retain high efficiency. We present H4-TEG, which incorporates the H4-Writer algorithm [2].

## 2. H4-Writer

H4-Writer [2] is an optimized four button keyboard that uses base-4 Huffman encoding. It utilizes minimized key sequences to enter letters with full access to error correction, punctuation, digits, and modes, as seen on a standard QWERTY keyboard. This was attained by branching the characters and commands into a tree having out-degree 4 at each node. H4-Writer's KSPC = 2.321. By pressing one of four buttons the user branches down the code tree until a leaf node is reached.

## 3 Design of H4-TEG

The human hand, with its four fingers, lends itself naturally to the H4-Writer concept. Each finger can represent a different branch in the base-4 Huffman tree, and a simple discrete pinching motion between the fingers and the thumb can be interpreted as a user selection.

The H4-TEG has four spandex finger bands and a Velcro wrist strap. Each finger band has a button connected to a colour-tagged wire running to the wrist strap where they are bundled and run to a keyboard-processing unit. The processing unit is encased in a plastic box with a belt clip for easy placement.

When fitting H4-TEG for use, the user centres each 3 mm diameter button on the pulpar surface of the distal phalange of the apt finger. When an actuator is triggered through a thumb-distal contact force of at least 1 Newton, the software fires a key pressed event.

Importantly, H4-TEG is untethered. The keyboard-processing unit communicates wirelessly at 2.4 GHz with the computer through a USB adapter, allowing 4.6 meters of freedom. The unit was extracted from a Microsoft Wireless Keyboard 800.

## 4. Software Interaction

Using the H4-TEG and H4-Writer Software users transcribe a block of five phrases drawn at random from a set of 500 [1]. The interface shows the phrase to be transcribed, the user's transcription, the user's input sequence, and the H4 keyboard. As entry progresses, users receive visual and audio feedback. With each button press (pinch), the keys are updated to show the characters accessible along each branch in the tree.

The interface sounds a "click" to indicate a key pressed event. The final key press of a Huffman sequence is marked with a "ding" audio cue.

For each phrase that is transcribed the interfaces shows the text entry speed (wpm), error rate (%), and efficiency (%) and then shows the average of these measures at the end of a block. A mistake if not corrected will be reflected in the error rate and a mistake that is corrected will be shown in the efficiency measure.

## 5. Conclusion

The Huffman base-4 Text Entry Glove (H4-TEG), is a text entry device that uses the H4-Writer software and finger-thumb pinching motions as discrete inputs. We hope that with improvements to the design of the glove, entry speeds will increase and physical exertion will decrease.

## 6. References

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- [2] MacKenzie, I. S., Soukoreff, R. W., and Helga, J., 1 thumb, 4 buttons, 20 words per minute: Design and evaluation of H4-Writer. Proceedings of the ACM Symposium on User Interface Software and Technology - UIST 2011, New York: ACM, 2011, 471-480.



# Icebreaker T-shirt: a Wearable Device for Easing Face-to-Face Interaction

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## Abstract

*This paper discusses the development of Icebreaker T-shirt with results from an experiment with shy users.*

## 1. Introduction

Initiating a conversation is a common challenge for shy people [2]; here, we introduce the Icebreaker T-shirt, intended to be worn in real-world social events, and aimed at increasing comfort feeling and familiarity between strangers by leveraging online social network information (e.g. Facebook) on clothing. Using advances of computer-mediated communication (CMC) with design principles of slow technology that value reflective experience of the user, we examine to what extent advanced technologies can improve social skills and may lead to more meaningful relationships in the real world.

## 2. Background

Various forms of online CMC have been reported to increase social relationships due to the fact that they allow users to focus on information content rather be overly concerned with social customs and non-verbal clues from interaction partners. However, these allow identity distortion, unrealistic expectations, and withdrawal from real-world activities; thus make face-to-face communication harder for socially anxious and low interpersonal skilled users. Social proximity applications (SPAs) in smartphones enable online information access in a pervasive manner. Our approach has similarities to SPAs like iBand<sup>1</sup> and SocialButton<sup>2</sup> that allow users with similar interests to share online information. However, most SPAs are deployed in unsophisticated objects causing low aesthetic value in “wear-ability” that can limit the

usefulness in sensitive social situations. iBand is closest to our approach; it uses an embedded infrared sensor in seeking other users in a close proximity whereas our Icebreaker T-shirt prototype uses Radio Frequency Identification (RFID) system to exchange users when they shake hands. However, none of SPA works so far has been designed to support shy users.

## 3. Design

Developed on a hypothesis that familiarity may enhance comfort and relaxation when meeting strangers, thus helping the wearer select new acquaintances while maintaining the naturalness of the social interaction and comforting property of clothing. The shirt is equipped with a set of RFID reader and tag embedded on the cuff of its long-sleeve. This allows two wearers to exchange identities when shaking hands. Next to it, there is a microcontroller designed to retrieve their public profile and preference from their Facebook pages using a smartphone (this feature was left out, and information of test subjects was pre-stored in the microcontroller used in the first proof-of-concept prototypes). The microcontroller matches users’ profiles and preferences. This results in a level of their social compatibility displayed using conductive thread and heated-sensitive paints. The more interests they have in common, the higher their compatibility level (conveyed with more colourful display) become.

## 4. Experiment

Four prototype T-shirts have been developed and tested with 11 self-report shy subjects in two speed-dating sessions: with and without the shirt. 73% said the shirt was helpful to their meeting with strangers. One said: “*It gave a sense of having something in common to begin the conversation, something we both were interested in. Whereas when we didn’t have the shirt, I felt we were only trying to make small talk.*” Although, the sample tested was small, our first experiment underlines some problems and potentials of the chosen technologies for improving interpersonal skills of shy people.

<sup>1</sup> M. Kanis, et al., “Toward wearable social networking with iBand”, *CHI '05 extended abstracts on Human factors in computing systems*, ACM, NY, USA, 2005, pp. 1521-1524

<sup>2</sup> L. Johannes, et al., “SocialButton – Mobile Technology Enhancing Social Interaction”, *Proceedings of the International Conference on Next Generation Mobile Applications, Services and Technologies*, IEEE Computer Society, DC, USA, 2007, pp. 14-18

# A System for Visualizing Pedestrian Behavior based on Car Metaphors

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## 1. Introduction

There are many accidents such as bumping between walkers in crowded places. One of reasons for this is that it is difficult for each person to predict the behaviors of other people. On the other hand, cars implicitly communicate with other cars by presenting their contexts using equipment such as brake lights and turn signals. The reason why people can intuitively understand car behaviors is that we have implicit knowledge of the context presentation methods of cars. We propose a system in this paper for visualizing the user context by using information presentation methods based on those found in cars, such as wearing LEDs much like brake lights, which can be seen by surrounding people.

## 2. System design and Implementation

The proposed system visualizes user behaviors based on the visualization methods used in cars. To do this, the user wears sensors and actuators such as LEDs and accelerometers since cars inform their turning or stopping contexts using turn signals or brake lights. Most people have implicit knowledge and intuitively recognize such meanings since they are familiar with the presentation methods for cars in their daily lives. Figure 1 illustrates a user wearing a *Jacket Type* prototype, and other types of devices. They have the following visualizing functions.

**Brake light:** When the button on the input device is pushed or the sensors detect the user is slowing down or stopping, the red LEDs on the back illuminate. **Blinker:** When the button on the input device is pushed, yellow LEDs on the back blink. **Hazard lights:** When the button on the input device is pushed, both yellow LEDs on the back blink. **Head lamps:** White LEDs on the chest illuminate to present the user's presence. Moreover, blinking head lamps will draw the attention of the surrounding walkers. **Engine sound:** The system outputs engine sounds using a speaker to present the user's presence based on the walking speed. **Horn:** When the button on the input device is pushed, the system outputs a horn sound from a speaker, and draws the

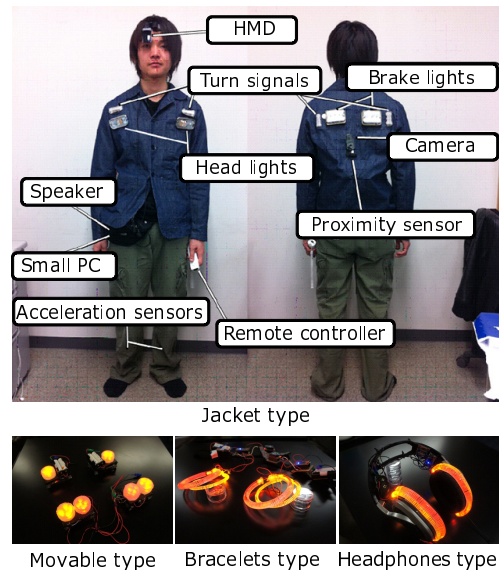


Figure 1. Our system.

attention of the surrounding walkers. **Rear view camera and backup sensor:** The user is aware the circumstance behind him/her from a sensor alarm or a rear view image.

In this system, we use Nintendo Wii remote controller as the input device, and wireless accelerometers (WAA-006) by Wireless Technology on the user's feet are used to recognize the user contexts.

## 3 Conclusion

We proposed a system for visualizing the user context for surrounding people for smooth walking environments. It visualizes the user behavior such as turning left or stopping, using car-metaphors such as wearing LEDs as brake lights and turn signals. Our preliminary evaluation confirmed that the system can show the intent of a user to the surrounding people in real environments, and our system is superior to systems using other methods (using texts or pictograms) in intuitiveness and quickness in presenting information.

# **ISWC 2012**

## **Design Competition**

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# Don't Break My Heart – wearable distance warning system for cyclists

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## Abstract

*London can be a daunting and scary place for a cyclist. In Kings Cross we have seen many cyclists hurt or killed on the roads, in London and all over the UK visibility for cyclists is an issue. 'Don't Break My Heart' is a piece of wearable technology using LilyPad Arduino, RGB LED, proximity sensor, conductive thread and fabrics to create an easily Velcro-ed on and off and highly visible alert for traffic traveling behind cyclists. A pulsating RGB LED heart is triggered by a proximity sensor if something is travelling close behind it. A green calm pulsating heart indicates a safe distance is maintained, an amber faster heart indicates that caution should be observed and a red rapidly pulsating heart indicates to the driver that they need to back off and give the cyclist some space.*

## Introduction



Figure 1. Shown pulsating green

'Don't Break My Heart' (Fig. 1) is a wearable, colour-coded distance warning system prototype for cyclists to wear on their back, whether that be a shirt,

coat or rucksack. It incorporates a sewable LilyPad Arduino microcontroller [1], RGB LED [2], proximity sensor [3], conductive thread [4] and fabrics to create an easily Velcro-ed on and off (moveable between garments & bags) and highly visible alert for traffic traveling behind cyclists.

## Development

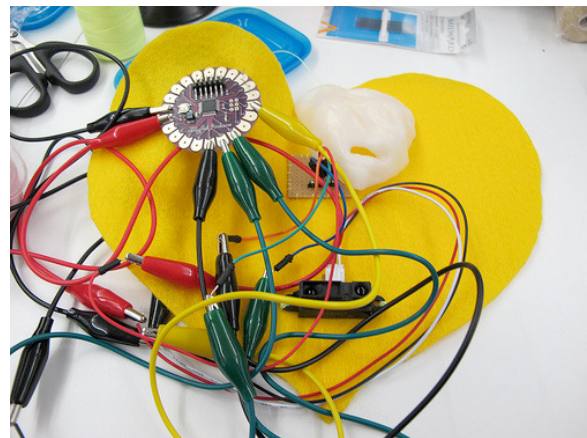


Figure 2. Testing with crocodile clips

I created the first iteration (Fig. 2) of this piece of wearable technology at Hondahack, in 2011, which was a developers' hackday held in London, sponsored by Honda and I created the work within a 12-hour deadline. I wasn't happy with the finished look of it at the time because I had rushed to put it together in time for the hackday presentations. So after the event and when I had the time, I unpicked the conductive thread and components, and put it back together as I wanted it to be.



**Figure 3. Shown pulsating amber**



**Figure 4. Shown pulsating red**

The completed 'Don't Break My Heart' wearable comprises of a pulsating RGB LED heart which is triggered by a proximity sensor when a vehicle is detected traveling close behind. I've used traffic light colour-coding for the super-bright RGB LED: a slow green pulsating light (Fig. 1) in the heart-shaped diffuser which I fashioned out of polymer, indicates a safe distance is being maintained, an amber faster light (Fig. 3) indicates that caution should be observed and a red rapidly pulsating light (Fig. 4) indicates to the driver behind that they need to back off and give the cyclist some space. As this is a prototype at the ideas stage, safe distances and final technology, such as sonar for proximity detection and other materials / components would be tested and confirmed later in the design process. The piece is portable between garments and bags as it uses Velcro to easily attach in to any surface. This also means the garment it is being worn on can be washed.

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# Temperature Sensing T-shirt (AKA: ‘Yr In Mah Face!’)

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## Abstract

*In my work I've been drawn towards the juxtaposition of self-tracking combined with social interaction and visibility of emotions, self-awareness and physical states via the use of sensors and actuators. I created a temperature sensing t-shirt to visualise personal physical data and how this has an impact on social occasions and relationships.*

## Introduction



**Figure 1. Temperature sensing t-shirt**

I'm very interested in the evolution of wearable technology, plus how audiences react and interact with my wearable works. This might be done via several methods such as looking at the history, development, limitations, future possibilities, plus present issues for users of wearable technology. For example, the durability of components e.g. sensors and how they are driven by ICs (Integrated Circuits) [1] and microcontrollers [2], battery size and power management issues, weight, clunkiness, design considerations for various user groups and acceptance by the public generally.

## Development



**Figure 2. Initial positing of components and design of work**

It's the availability of sewable electronics and sensors in particular that allowed me to bring my ideas to fruition. I'm very interested in how people behave in social situations and express emotions. I use sensors to detect physical signs such as heart rate, temperature, proximity and movement. I integrate the sensors and other electronics as part of my overall design with fabrics and e-textiles (Fig. 2), I also repurpose existing

electronic devices, especially those that are open source and I can easily obtain their schematics and coding files to rewrite.



**Figure 3. Sewing of conductive thread seen from the underside of the design**

The contemporary styling of the LilyPad Arduino component range [3] has made them more attractive to work with, for example the LilyPad Arduino Microcontroller board is round, has petal shaped pads for sewing with conductive thread [4] instead of soldering, the range is purple and is light and fairly flat. This styling has helped change how people regard wearable technology and electronics for wearable technology, which is no longer comprised of cold, bulky sharp, boxy & ugly components that you might prefer to remain hidden. This allows me create much more elegant work with electronics and incorporating the technology into the design of the overall work.

An example of my work looking at social interaction is 'Yr In Mah Face': a temperature / mood sensing t-shirt (Fig. 1), it takes Celsius temperature data from the wearer via a small temperature sensor attached on the chest area of the shirt. In the code that drives it I've written an algorithm that averages the temperature taken from the sensor and then visualises the results via controlling the current to light an appropriate set of LEDs (Light Emitting Diode) [5] on the shirt. The LEDs are contained within two fabric feline styled heads as eyes. One head is green to reflect feelings of cool, calm and collectedness and the other is red to relate to feelings of stress, agitation or getting 'hot under the collar'. The LEDs or 'eyes' light up and fade depending on the temperature being recorded from the wearer's body. All the electronic components are connected and sewn together with conductive

thread which is incorporated into the design of the work (Fig. 3).

I intended the shirt to be worn at social occasions such as networking events where people often meet and talk to strangers, and are projecting their self-image whilst making quick, spur of the moment judgments about others.

I'm interested in visualising physical data and how this has an impact on relationships. In wearing the t-shirt and speaking to people about it, I have found some are comfortable about indicating their possible emotive state, whereas other people are decidedly uncomfortable with the idea of making any emotions or interpretations of physical data public.

My temperature sensing t-shirt is a fun experiment, though I'm very interested in how various sensing technologies, including temperature sensors, can have broader and varied uses. For example, in a society where more of the population is living to a ripe old age, then smart wearables that incorporate temperature and other sensing modules may help older people who might need their health monitoring constantly but wish to live at home or be mobile. Also, for various lifestyle and sporting uses, such as comfortable sports clothes, fitness monitoring and extreme environment wear.

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# Twinkle Tartiflette – an Arduino driven interactive word and music artwork

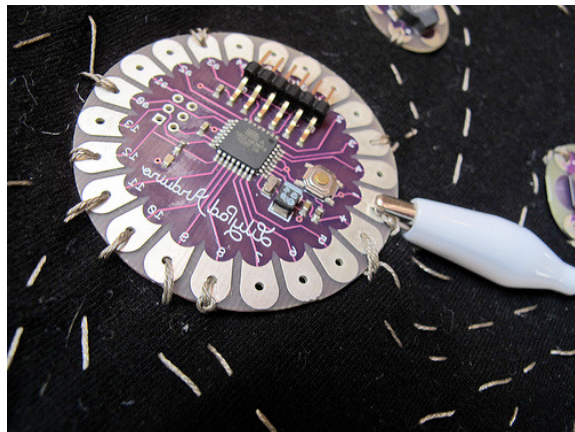
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## Abstract

*LilyPad Arduino is a great platform for rapid prototyping for my standalone interactive art projects and wearable artworks. It's also a fun way to learn about electronics and programming. It allows the user to combine electronics and textiles by way of a sewable microcontroller and suite of components. Twinkle Tartiflette is an interactive wearable in the form of a word and music artwork.*

## Introduction



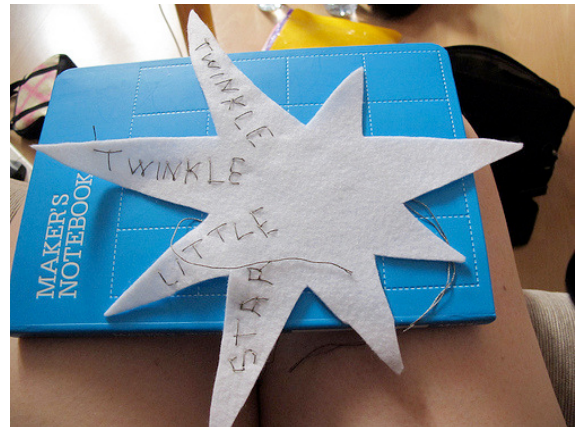
**Figure 1. LilyPad Arduino**

I decided that I wanted to combine words, image and sound into an interactive experience, brought to life by touching embroidered words with a stylus on a shirt and using the LilyPad Arduino [1], a sewable microcontroller [2], with conductive thread [3] and electronic modules.

## Development

I began to think about how I'd build this work and firstly decided on re-using the frequencies for notes

worked out for a favourite nursery rhyme, 'Twinkle Twinkle Little Star' [4], that I'd used in another interactive artwork. I chose to transfer the first two verses of the aforementioned nursery rhyme word for word onto felt stars, one star for each verse.



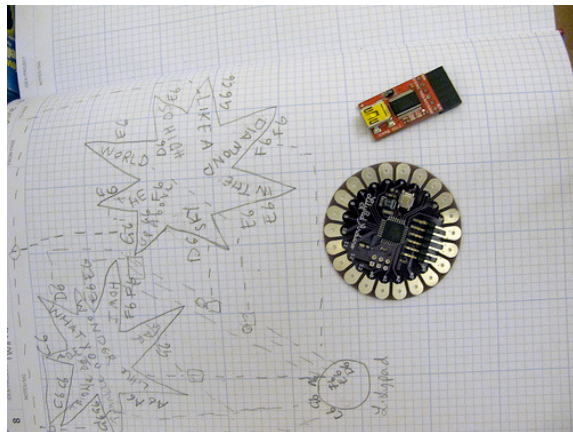
**Figure 2. Embroidering words in conductive thread onto stars**

There are six notes in the first two verses of 'Twinkle Twinkle Little Star', so I needed to map out a schematic for the conductive thread to pass from the words to the LilyPad Arduino (Fig. 1), joining each word to the right note pin on the LilyPad. The first action was to cut out two star shapes and begin embroidering the words onto them with conductive thread (Fig. 2).

With the word stars completed it was time to start sewing the main sewing schematic onto the shirt, I'd mapped the six notes to the words of the nursery rhyme and then the words on the stars back to pins dedicated to notes on the LilyPad Arduino (Fig. 3).

After an intensive two weeks of sewing, I had sewn all the embroidered words back to the correct notes on

designated pins, I also added the buzzer and battery modules to the shirt. There were some interesting insulation and bridging issues to be solved between the various paths of conductive thread crossing each other on the shirt and I hid all the bridges for thread that crossed other thread paths on the underside of the shirt. I was then ready to write and compile the code and test to see if it would compile (work). The code I have written uses the speaker module to produce simple musical notes via connecting to the words with a stylus and completing a circuit. I used a note chart to match frequencies to the different notes that could be played on the piezo buzzer [5] I had sewn to the shirt, the frequencies became part of the code to tell the buzzer which note to play.



**Figure 3. Schematic of tracks of conductive thread from words to LilyPad Arduino pins**

All that remained to do was tidy up the sewing, ensuring there are no trailing bits of conductive thread to cause short circuits and gluing down any thread looking like it was going to stray or come undone with fabric glue (Fig. 4). The shirt was then ready to be worn and one could play the tune of 'Twinkle, Twinkle, Little Star' via the stylus when required.



**Figure 4. Finished Twinkle Tartiflette**

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# Reconfigurable Electronic Textiles Garment

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## ABSTRACT

In collaboration with researchers at NASA's Johnson Space Center, we have created a reconfigurable electronic textiles garment with interchangeable functional swatches that perform various tasks such as a light sensor, bump sensor and activation of vibrating motor.

## 1. DESIGN OBJECTIVES

The goal of this project was to develop an astronaut flight suit or stand-alone garment that allows for optimum mobility and comfort while supporting quick attachment of simple display and control elements mounted on fabric swatches. The garment must provide power to the swatches and the ability to attach up to 8 different swatches simultaneously at different locations. Swatches should utilize attachment methods appropriate to positioning on the body. Students should deliver the functioning garment with at least two example swatches for demonstration. This would be an Arduino based system.

The design objectives were as follows:

- Optimum mobility and comfort for user
- Full circuit within suit, reaching to all eight attachment locations
- Three functional swatches
- Ergonomically designed suit for swatch use
- Utilizes affective attachment and detachment methods

## 3. DESIGN CHALLENGES

### 3.1 Swatch Locations

Swatch locations need to be easy for the user to access, on parts of the body that allow for movement and comfort, while still being able to be feasibly connected to the Arduino board at the back of the suit. We have placed the eight swatch locations at the most ergonomic locations manageable without interfering with mobility.

To determine swatch locations, we assessed mobility and reach to body locations, sensitivity of the skin over the body surface (assuming some necessary applied pressure to attach, detach, and/or interact with swatches), and visibility of body areas (assuming some or all swatches needing visibility for effective interaction).

Swatch locations are depicted in Figure 1.

### 3.2 Layering

To make sure that the traces did not interconnect, we needed to create a multi-layer circuit within the suit. Although the suit calls for routing to eight separate locations (which could require up to eight layers of traces), excessive layering would not work in conjunction with a suit that would be comfortable and wearable. We condensed the eight layers into two by applying conductive

traces by stitching with a lockstitch machine, with conductive yarn in only the bobbin thread. By adjusting machine tension, we were able to restrict the conductive trace to one side of the fabric, using the fabric to insulate traces on one side from traces on the other side. In this way we were able to put four layers into one, condensing the circuit to two layers. Traces on layers in physical contact were insulated with fabric paint.



Figure 1. Reconfigurable e-textiles garment, showing swatch locations



Figure 2. Garment interior and exterior layering.



### 3.3 Trace and Interconnect Layout

Each of the eight required swatch locations have conductor connections, each of which connect to a small location on the back. Each location needs to be well placed so that overlap of the conductive traces does not occur. Shown below is how we overcame this complication, by staggering the traces to fit closely together without touching, and stitching the layers so that the conductive thread is on the top for the vertical traces, and on the underside for the horizontal layers.

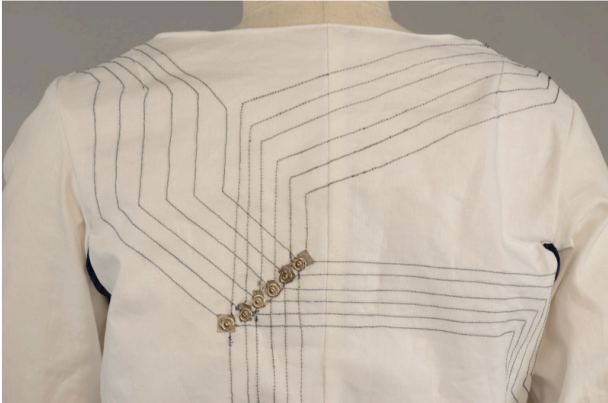


Figure 3. Central connection points for microcontroller showing stitched traces.

### 3.4 Stitch and Trace Crossing

Where traces meet seams that still need to be sewn, traces need to be matched up exactly, and stitched precisely using non-conductive thread to create a simultaneous electrical and mechanical connection. This leaves very small margins of error, requiring precision in patterning and stitch layout.



### 3.5 Swatch Attachment

Each of the six central points of connection need to match up exactly to each individual swatch to make sure that an electrical connection is being made, and the circuit is completed. Thus we needed to take into consideration what type of fastener to use, because it has the dual purpose of securing the swatch in place, and completing the circuit. We used rare-earth magnets attached with adhesive conductive tape for ease of construction. Controlling the polarity of the magnets allowed us to ensure that the swatch could not be attached upside-down or misaligned.



### 3.6 Connecting Suit Layer

All eight swatch locations were routed back to one central microcontroller attachment location. We used the female side of compression snaps to connect the 2 layers of the suit together, and the male side to connect the Arduino board to the meeting point of all the traces.



## ACKNOWLEDGMENTS

Our thanks to the University of Minnesota, NASA, and the Minnesota Space Grant.

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# Context aware signal glove for bicycle and motorcycle riders

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## ABSTRACT

For bicycle and motorcycle riders, visibility is a constant concern for safe riding. For the designer, minimizing additional demands on the rider's attention is just as crucial when the device will be used while operating a vehicle, especially a bicycle or motorcycle. This illuminated riding glove uses off the shelf sensors to recognize common hand gestures used by riders and actuates appropriate LED patterns to enhance the visibility of the gesture. The configuration of LEDs also translates the gesture to an illuminated directional chevron to aid other road users who may not be familiar with the left and right turn hand signals used in North America. By equipping the device to recognize existing hand gestures, activation of directional LED signals is simplified allowing the rider to focus on riding while the glove responds to and extends the visibility of the rider's hand gestures. This context awareness allows the device to cooperate with the rider, rather than asking the rider to interact with the device.

## Categories and Subject Descriptors

H.5.2 User Interfaces

## General Terms

Design, Human Factors.

## Keywords

Context awareness, gesture recognition, wearable technology, emotion.

## 1. INTRODUCTION

After helmet use, one of the most important things to consider in bicycle and motorcycle operation is visibility. This concept seeks not only to enhance visibility through the addition of illuminated LEDs to the rider's glove, but also extend the ability to use standardized hand turn signals into the night hours. It is important that any added functionality not create additional demand on the attention of the rider. To achieve this increased functionality without added workload, sensors are employed to recognize common hand gestures for cyclists and motorcycle riders, and actuate the appropriate LED pattern. While adding visibility, the gestures are also translated into directional chevrons, or arrowheads, as some road users may not be familiar with the hand signals used in North America for signaling turns, due to infrequent use or distraction.

## 2. MOTIVATION

The addition of blinking lights to gloves as a means to increase rider visibility for bicyclists and motorcyclists is not a new one [1]. The novelty and value are instead derived from the recognition of standard hand gestures. By recognizing the gestures used in signaling intention to other road users, the rider can actuate an appropriate LED pattern to supplement the hand signal without having to modify their signaling habits with one more button push to actuate yet another device. This context awareness helps move the glove beyond being a device to be interacted with to one that is in cooperation with the rider. Instead of demanding the adoption of new behavior, the device affords the existing behavior, allowing the rider to focus on their ride. For diagrams of the standard hand signals and common gestures supported see figures 1 through 4.

Other road users may not be familiar with or have forgotten the hand signals due to non-use. These drivers are also aided by the translation of the hand gesture to an illuminated directional chevron. Additionally, in low light a vehicle operator who may be aware of the hand signaling system may not see the outstretched arm, or be able to differentiate between a bent elbow and an outstretched arm.

The glove also supports the rider's expression of anger. Humans are emotional, and supporting that emotion is crucial in creating a connection between human and object [2]. The extended middle finger is known in North America as a dubious gesture, and is one commonly used to express the rider's disapproval or anger with other road users when the rider perceives a disregard for their safety.

## 3. FUNCTIONALITY

The glove prototype uses flex sensors, a basic tilt switch, off the shelf 3mm high flux LEDs, and an Arduino Pro Mini to recognize gestures and actuate the LEDs.

The flex sensors are located at the index and middle fingers, and function to recognize released grip from the handlebars and to differentiate between the open hand position for turn signals, pointing with the index finger, or gesturing with the middle finger.

The tilt sensor functions to detect the orientation of the hand to differentiate between left turn signaling, a horizontal open hand, and right turn signaling, a vertical open hand.

This combination of sensors recognizes and differentiates between resting state and 4 gestures common while riding:

### 3.1 Hand grasping handlebar, closed hand.

When both flex sensors are flexed, all LEDs are turned off. When the hand is closed, the hand is assumed to be wrapped around a handle bar, with no signaling occurring.

### 3.2 Right turn hand signal

When both flex sensors are open and not flexed, and the tilt switch is in the vertical position, LED circuits D and L are repeatedly activated and deactivated at 500 ms intervals to create a blinking chevron or arrow head symbol pointing to the right when hand is oriented vertically as long as sensor state remains the same. See figure 1.

### 3.3 Left turn hand signal

When both flex sensors are open and not flexed, and the tilt switch is not in a vertical position, LED circuits D and R are repeatedly activated and deactivated at 500 ms intervals to create a blinking chevron or arrow head symbol pointing to the left when hand is oriented horizontally as long as sensor state remains the same. See figure 2.

### 3.4 Index finger extended to point

When the index finger flex sensor is open and not flexed and the middle finger flex sensor is flexed, the tilt sensor is ignored. LED

circuits D and L are activated and illuminated constantly creating an illuminated chevron or arrowhead symbol as long as sensor state remains the same. Illuminated chevron points in same direction of finger regardless of hand orientation. See figure 3.

### 3.5 Outstretched middle finger

When the index finger flex sensor is flexed and the middle finger flex sensor is open and not flexed, the tilt sensor is ignored. All LED circuits (X, D, R and L see figure 5) are activated and deactivated repeatedly at 250 ms intervals creating a flashing diamond as long as sensor state remains the same. See figure 4.

## 4. ACKNOWLEDGMENTS

Thank you to Dr. Lucy Dunne and Mrs. Stephanie Carton for advice, assistance, and prototyping help.

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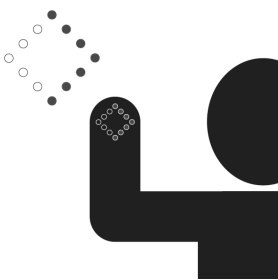


Figure 1: Right turn hand signal

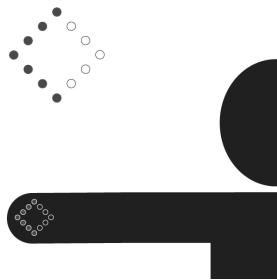


Figure 2: Left turn hand signal

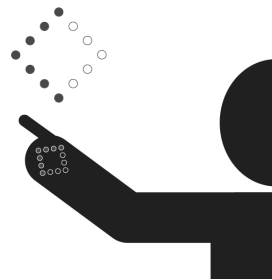


Figure 3: Pointing

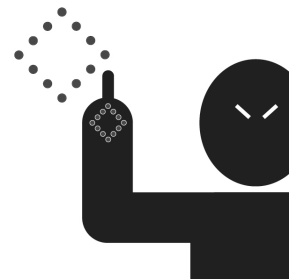
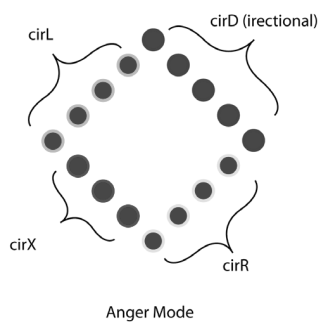
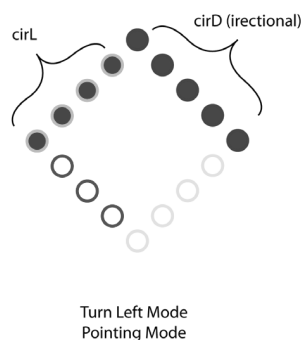


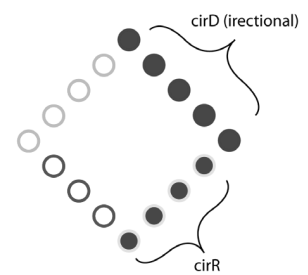
Figure 4: Obscene Gesture



Anger Mode



Turn Left Mode  
Pointing Mode



Turn Right Mode

Figure 5: LED circuit diagrams

# Solar Family

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## ABSTRACT

This mini-collection of three garments explores the concept of using solar power to change the garment's aesthetic as well as functionality. The two main concepts of the collection are sustainability and wearable technology. The garments offer on-the-go solutions to changing garment's appearance and charging electronic devices.

## Keywords

Solar, photovoltaic, e-textiles, wearable technology, fashion

## 1. CHILD'S GARMENT

Since this child's dress was designed to be non-traditional to current trends, non-traditional fabrics were selected. The bodice and the pockets of the dress are made of fine white canvas. The skirt is made of light blue vinyl with leather texture print, mounted on woven base. For comfort the dress is lined with white muslin. Lining also serves as a barrier between the body and integrated technology.

### 1.1 Concept

The objective of this design was to create an outfit that uses solar power, generated by photovoltaic panels incorporated in the garments as a power source for decorative and interactive feature of the dress, such as spinning flower. The goal of the design was to create something that can be both technology-forward and wearable, and will simultaneously entertain and amuse the child.

### 1.2 Technological Functionality

Solar energy is collected by six photovoltaic panels located in pairs down the front of the dress (*figure 1 and 2*). The collected energy is transferred to a battery pack, located under the skirt of the dress. Activation of the dress's interactive component takes place when an interactive squeezable ball, located in the right pocket of the dress is squeezed, closing a conductive fabric switch and activating the flower, located on the left side of the chest. As the flower activates (*figure 2b*), it turns on a motor and the flower spins. As the interactive ball is released, energy flow stops and the flower rests. The interactive ball is made of two layers of conductive fabric separated by a piece of open cell foam with a hole in the middle. As the ball is squeezed, the layers of the conductive fabric touch and close the switch to activate the flower. As the ball is released, the foam recovers to separate the fabric layers and open the switch. To add interest to the flower, a string of colorful beads was added to each petal, so that as the flower spins, the viewer sees different sparks of color.

## 2. MOTHER'S GARMENT

The design for the mother's garment was primarily inspired by the idea of the futuristic family. Further exploring the aesthetic abilities of wearable technology we used electro luminescent

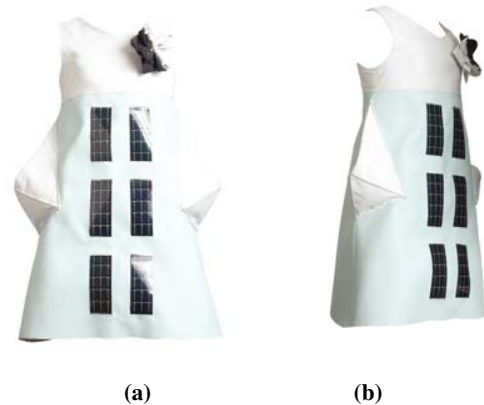


Figure 1: Child's Garment Front (a) and Side (b)

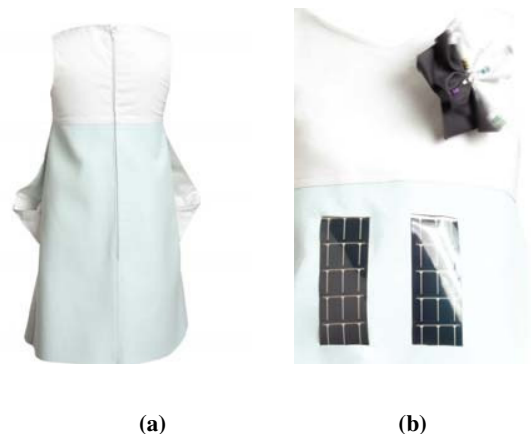


Figure 2: Child's Garment Back (a) and Flower Detail (b)

wiring on the skirt to allow the wearer to have multiple options for this garment. The sculptural silhouette of the garment was inspired by the Urban Kaleidoscope created by Marco Hemmerling (*figure 3 and 4*) and was constructed of a non-traditional fashion fabric: vinyl, and vinyl/mesh laminate.

### 2.1 Concept

Solar energy in this garment was employed primarily for aesthetic purposes. This project was designed to harness solar energy in the service of aesthetic innovation in wearable technology.

### 2.2 Technological Functionality

Electro luminescent wires were applied to follow the contours of the skirt (*figure 4b*). The four solar panels on the upper back collect energy from the sun which charges a battery pack located under the skirt. A toggle button, on the front left waist, controls the state of the Electro luminescent wires. There are four cycles

the user can choose from: solid lights, fast blinking, slow blinking, off.



Figure 3: Mother's Garment Front (a) and Side (b)



Figure 4: Mother's Garment Back (a) and Skirt Detail (b)

### 3. FATHER'S GARMENT

The father's jacket was inspired by the idea of a male architect who uses his bicycle as a means of transportation to work. The garment is a biking jacket with an urban edge in order for him to wear his jacket during the commute and potentially also at work. The shell of the jacket is made of waterproof-breathable dark gray Gore-Tex with black mesh lining for better ventilation. Vents are located near the core of the body and at the lower back to cool the areas of the body that hold the most body heat (figure 5b). Black reflective piping in the front seams and under the pockets, outlines the contour of the body as to increase visibility when bicycling. Solar panels are placed on the front part of the sleeves for better exposure to the sun while biking (figure 5). On the back bottom (figure 6) of the jacket mesh-covered vinyl is placed over luminescent wire design to protect wire from dirt. An adjustable collar allows the user to cinch it when cold, or release it when warm.

#### 3.1 Concept

The objective of the design was to create a garment that would use solar energy to power functional elements of the garment.

### 3.2 Technological Functionality

The solar system in the father's garment is set so that solar panels are wired to a battery pack, located in the right pocket. A toggle button in the pocket regulates the lights in the back. The user can choose from four settings: solid light, fast blinking, slow blinking, and off. The other set of wires goes into the left pocket, which contains an outlet for a USB cord; this can be used to charge electronics. The solar panels are arranged to collect solar energy while in a biking position.



Figure 5: Father's Garment Front (a) and Side (b)

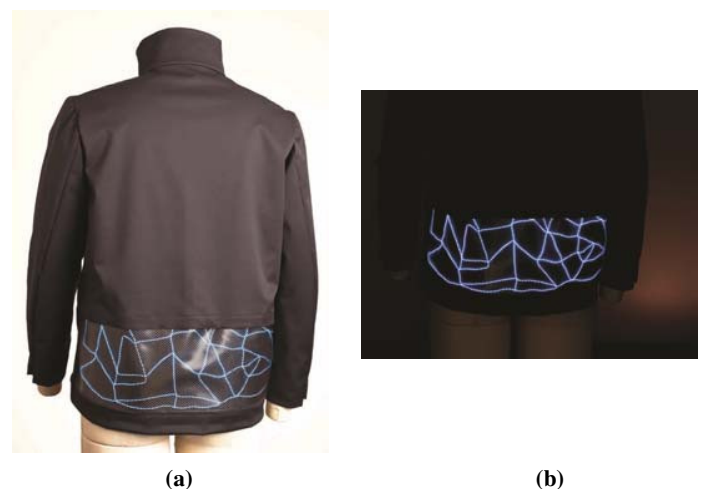


Figure 6: Father's Garment Back (a) and Back Detail (b)

### 4. CONCLUSION

Solar-powered garments open a new venue to be adopted and elaborated upon in wearable technology field. In this collection unusual fabrics were used to give edge and avant-garde feel to the looks. The solar panels were incorporated into designs to emphasize the idea that "new" wearable technology can also be fashionable. Lastly, solar panels with improve sustainability of the technology in the garments.



# Fairy Tale Kinetic Dress

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**Abstract**—This kinetic white dress is made with Arduino Uno and a mini servo motor to give a kinetic reaction when wearer pressing a button on the left side of the dress. This dress is made for kinder garden teachers and mothers to interact with children to develop children's' emotional and intellectual. Wearers can use the dress as backgrounds of fairy tales using various characteristics. At this time, a worm and a butterfly were prepared with light emitting diodes (LEDs) lighted on. The dress is designed to interact when educating and playing with children with fun, and enjoyment; attract children's attentions; and create close connections between kinder garden teachers and mothers with children. This dress is multi-use and it can also be worn in special occasions such as casual parties or as a bridal dress for unique styles and entertains. To maximize movement of the dress from the servo motor, many experiences have been done with various materials and details.

**Keywords**—*Arduino; servo motor; dress; wearable technology*

## I. CONCEPT

The Fairy Tale Kinetic Dress contains three major concepts: interaction, fun, and multi functions. This dress is made for kinder garden teachers and mothers to interact with children to develop children's' emotional and intellectual. Fairy tales can influence positively on children to create their roles and self identity [1-2].

First, when telling fairy tales with preschool children, kinder garden teachers and mothers can use the dress to tell interactively fairy tales. The dress becomes a site and a background for stories and flowers, ropes, and other details are moving. There is a butterfly is paired with a worm that is main characters and light emitting diodes (LEDs) lightened up. With kinetic effects on the dress, wearers can attract children's attention and motivate interests. If other main characters are developed in the future, the dress can be used as backgrounds for various stories. By wearing the dress, wearers can play interactively with and be involved actively with children.

Second, dress influences on student's perceptions on teacher's characteristics [3]. Kinder garden teachers can wear the dress and by easily pushing buttons, teachers can make fun situations and keep children's attentions. Not just wearing regular garments, teachers can create fun and enjoyable circumstances and vibrant teacher's images to children. The dress is expected to make distances between teacher and preschool children closer and create strong inner connections. Also, teaching lessons and etiquette education classes can be

done with children by telling fairy tales by giving fun at the same time.

Third, the dress can be worn for various occasions. For instance, the dress can be worn for at work for kinder garden teachers and mothers when they are at home or go out with preschool children. Also, the dress can be worn for special occasions such as casual parties. The dress can create a starting point of conversations with others at a party and the dress can be used as a method of expressing their feelings. Even, the dress can be worn by brides that are looking for unique and fun dresses.

## II. TECHNOLOGY

In the Fairy Tale Kinetic Dress, Arduino Uno sized in 75 x 53 x 15 mm controls mini servo motor (sku: ROB-09065) sized in 22.8 x 11.8 x 20.6mm and weighted in 9g [4]. The mini servo motor's operating voltage is ranged from 4.8V to 6.0V, operating speed is 0.10sec/60 degree, and rotating range is less than 170 degrees [4]. The mini servo motor is designed to be controlled by a square momentary push button switch (COM-09190) sized in 12mm [4]. Battery pack is made of 4AA and with on and off switch included. The butterfly and a worm are made of two clear white LEDs and 2 AA battery pack. The button is connected to number 2 and the mini servo motor is linked to number 9 of the Arduino Uno board. The mini servo motor is programmed to rotate clockwise less than 170 degrees and after 15 micro seconds, the mini servo motor rotates less than 170 degrees into opposite clockwise direction. Thus, if the wear pushes the button, the motor rotates in two different directions to move and shake details of the dress. The three Triple Output LEDs are 5mm sized and viewing angles are 30 degrees [5].

## III. EXECUTION

To maximize kinetic functions of the dress, the mini servo motor attaching position on the dress, types of materials and connection methods are tested before finalize the design of the dress. First, to use mini servo motor, the curves of the body and the surface of the dress should not impede the rotation of fans attached on the motor. Eight areas of the body suggested by Gemperle's wearability research were referenced, and among them, three areas on upper body and one area on upper arms tested to attach the servo motor [6]. When the servo motor rotates, near the collar area and shoulder was selected as there are lack of obstacles such as high surfaces created by dress and body.

Second, fabrics types and string types are connected to servo motor to evaluate degree of motion ranges. String types moved more and even after finish of the servo motor rotation, string keep shaking as for the lightweight. Thus, string types are selected to use, and to make the movement of strings bigger, additional attachments were added to strings. The strings and added materials need to be lightweight not to pull down the fans of the servo motor. After various evaluations, used materials are threads, knit yarns, stretchy clear cord, fiber optics, polyester pom-poms, and polyester fabric bloom flower decorations.

Third, the motor is attached with two pole nylon fan. If the horizontal length of the fan is longer, the movement of the motor becomes bigger. However, there are limitations to make the fan size bigger such as the fan should be lightweight as the servo motor cannot hold heavy fans. The fan should not soft or able to easily vent, as if the fan is soft and easily vent, the fan cannot stand the weight of the detail attachments and/or tension and the fan touch the surface of the dress which limits the rotation of the servo motor. Also, the fan can touch wearer's face or neck so the size. Thus, the fan is made of 3inch polyester film for each fan and the outer layer is made of 4 inch felt to easily connect with other attached detail materials by sewing. Attached detail materials are connected to fans and the surface of the dress; and some parts of threads and attached materials are connected to spread movements of the servo motor to the whole area of the dress.

Electronic devices are attached in felt pockets inside of the dress and devices can be easily take off and put in to be detached before washing or change batteries.



Figure 1. Fairy tale dress



Figure 2. Details



Figure 3. Butterfly and a worm

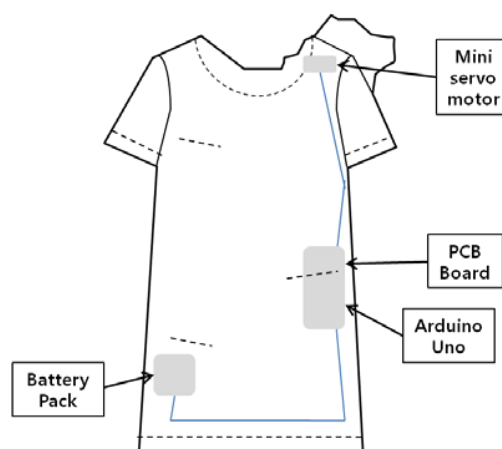


Figure 4. Design specifications

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# The Photonic Bike Clothing III – For Enthusiastic Biker

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## Abstract

The objectives of this work is to seek systematic modular design methods for smart photonic clothing for biking based on **lighting and heating** technology related to smart clothing, and to present a variety of modular design models based on conductive textiles, heating device and lilypad-LED module assembly technology. On the basis of the LED module technology, a jacket with smart photonic function was designed and the heating pants was made using heating moduel the focus on the biker's safety and its protection function. The main concept is "For Enthusiastic Biker", a professional job holder who commutes by bike, and it uses various fabrics and heating-modules with proper functionality for the warm photonic bike clothing.

**Keywords** : photonic clothing, enthusiastic biker, Lilypad LED module, heating modules,

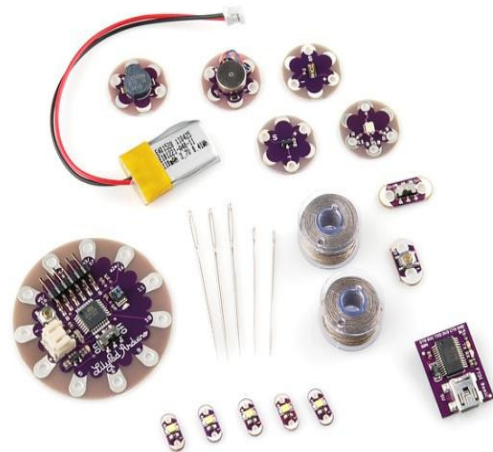
## 1. Concept and Fabrics

**Table 1** summarizes the mood board "For Enthusiastic Biker" and the type of fabrics in the clothing. The exterior design has been developed for the outdoor biker based on eco-friendly lifestyle. The core aspect of the design is to create a professional worker's suit fit for cycling in the winter. So, we have decided to make a LED jacket and heated pants. It was made with felted wool, waterproof fabric, the breathable mesh fabric, and self reflective textile.

## 2. The photonic module






**Figure 1** shows the photonic module in this work. The **LilyPad** Arduino is a circle, approximately 50mm

(2") in diameter. The board itself is .8mm (1/32") thick (approximately 3mm (1/8") where electronics are attached). The LilyPad Kit(KIT-10354, sparkn electronics, USA) is a great way to get started with the LilyPad e-textiles platform. Using the parts in this kit you can create e-textile projects that sense and react to light and temperature with LEDs, buzzers and even vibrating motors. The brain of this outfit is the Arduino-compatible LilyPad Simple Board, which we can program with the included LilyPad FTDI breakout. LilyPad is a wearable e-textile technology developed by Leah Buechley and cooperatively designed by Leah and SparkFun. Each LilyPad was creatively designed to have large connecting pads to allow them to be sewn into clothing. Various input, output, power, and sensor boards are available. They're even washable.



**Figure 1:** The photonic modules using in this clothing.

**Table 1:** The mood board for design and type of used fabrics

Concept	<p style="text-align: center;">For Enthusiastic Biker</p> 
Type of Fabrics	 <p style="text-align: center;">Twill with waterproof and file double woven</p>
	 <p style="text-align: center;">Felted wool fabrics</p>
	 <p style="text-align: center;">File taffeta</p>
	 <p style="text-align: center;">Reflective fabrics</p>



**Figure 2:** The photonic modules using in this clothing.

### 3. The heating module

**Figure 3** shown that the heating module (KLK-5000, Korea) is used carbon flattened heating goods, battery, and charger. The surface temperature is 50 ~ 70 °C. The Battery's capacity is Li-Ion7.4V, 2,200mAh. The size and weight are 5.1 x 7.4x 2.3 cm and 126g, respectively. The charge time is 2~3hr and duration time is 6hr at 40 °C. This heating module is applied to the pants.



**Figure 3:** The heating modules using in this clothing.

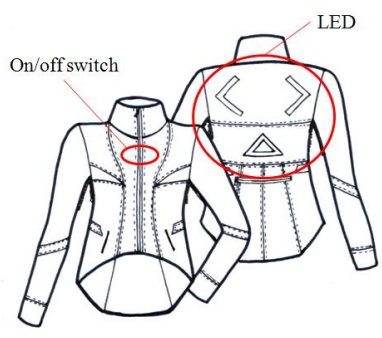
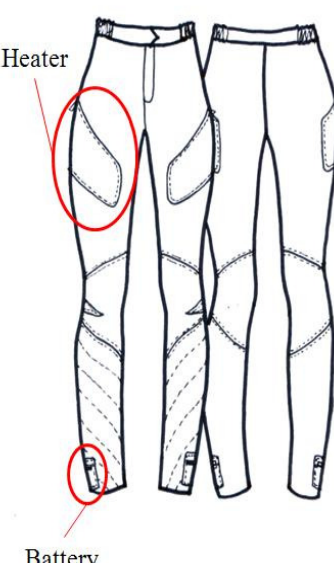
### 4. Photonic Bike Clothing III – For Enthusiastic Biker

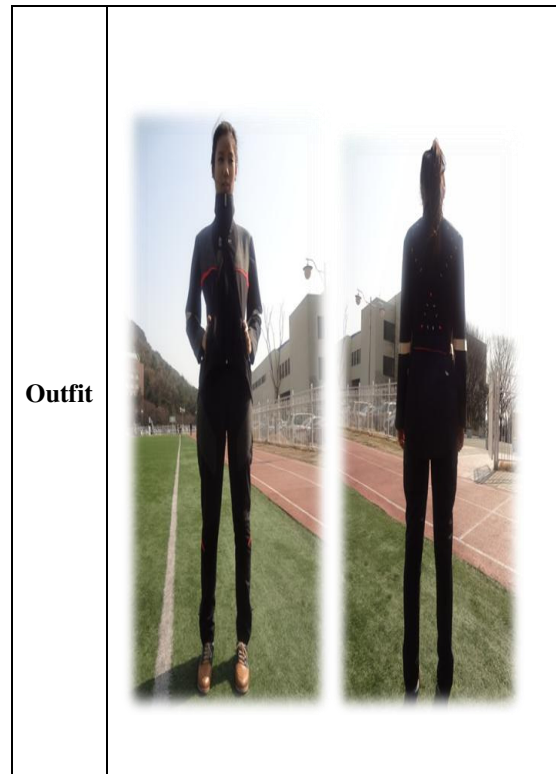
**Table 2** shows the flat figure and the outfit of the photonic bike clothing III for outdoor bikers. To increase visibility during cycling, the photonic modules are attached to the back parts of the jacket. Included on the top of the center panel is a switch storage area for valuables and access to the battery. The back of the



jacket is zipped for storage. This wearable technology provides the urban biker with added safety and the comfort of use on the road. The pants feature is ergonomics patterns to ease and warmth the biker during cycling.

**Table 2:** The flat figure and the outfit of the photonic bike clothing III - For Enthusiastic Biker

<b>Flat Figure</b>	<p><b>Jacket</b></p>  <p>On/off switch</p> <p>LED</p> <p>Front Back</p>
	<p><b>Pants</b></p>  <p>Heater</p> <p>Battery</p> <p>Front Back</p>



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# Wearable Multimodal Warning System

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## ABSTRACT

In this paper, we discuss the foundation research, design process, and resulting design for a multimodal warning system that is both wearable (comfortable) and perceptible to the user (functional). This project is based on a special collaborative project with NASA Johnson Space Center and a Junior-level studio course in the Apparel Design program at the University of Minnesota.

## 1. INTRODUCTION

When an emergency is detected, crew members aboard the International Space Station must be alerted immediately. The most appropriate method of alerting a crew member depends on their current activity. Crew members are constantly working on different projects that involve multiple senses, and they might fail to receive an emergency alert if it is delivered in only one modality. One approach to ensuring that the alarm is perceived is to deliver the alarm in multiple modalities.

Quality and placement of each modality must be considered. The system design will be determined through a series of prototype testing in order to ensure the user has the best perception of each alarm.

The goal of this project was to design a stand-alone garment that activates a warning by stimulating at least three senses simultaneously. The chosen modalities are: audio, tactile, and visual. Because one or more senses may be disabled, alarms should have the best possible chance of being perceived at any given time.

### 1.1 Design Objectives

- Research and determine how perception is affected by the quality, placement, and intuitive reaction of each modality.
- Determine placement of audio, visual, and tactile alarms on the garment.
- Design the garment so that all 3 modalities do not feel noticeable when system is not in use.
- Implement alarms of varying types of urgencies that can be stimulated via the user or via an outside source.

## 2. RESEARCH AND DEVELOPMENT

### 2.1 Device Placement

Based on background research informed by Gemperle et. al [1] and Wickens et. al [2], the following device placement guidelines were determined:

- Choose areas of low movement /flexibility
- Choose areas larger in surface area

- Device placement should be relatively the same size across adults
- Choose areas that are also close to the ear (for audio perception), sensitive (for tactile perception), and visible (for visual perception).

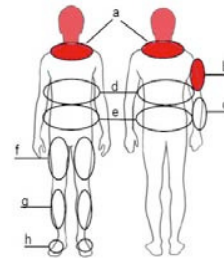


Figure 1. Device placement locations derived from Gemperle et. al [1].

### 2.2 Stimulus Parameters

Based on background research informed by Wickens et. al [2] among others, as well as original experimental research testing placements and stimulus patterns in each modality, the following parameters were determined for each stimulus modality:

- Audio: Frequency 1000-4000 Hz. Raise pitch and volume to increase urgency, staying below 85 dB.
- Tactile: Stimulus between 80-500 ms, increase duty cycle to raise urgency. Use tactons to encode information.
- Visual: Red = warning, yellow= most visible color. Movement helps in getting attention, faster movement increases urgency.

### 2.3 System and Garment Design

The final garment design is depicted in Figure 3 and illustrated in the preceding figures.

#### 2.3.1 System wiring and device placement

Figure one shows a technical sketch of the final garment. Speakers are placed on the shoulders, LED lights are placed on the collarbone, LED lights are also placed at the forearm, and a user-activated button is on the forearm. Mapping the wires throughout the garment can then be determined by following the color coded lines that span across the garment.

Seen in the back are 2 vibrating motors placed on the shoulder blades. All of the wires from the speakers, lights, and motors are mapped into a pocket located on the back of the garment ending just below the back waist. This pocket holds an Arduino board, a switch, and other circuitry.



(a) Front



(b) Back

**Figure 2. Garment wiring harness and device placement.**

### 3. TYPES OF ALERTS

**Table 1. Garment alert types**

Automated Alert 1	Low Urgency	Activates in a low state of emergency where response time is not a critical factor
Automated Alert 2	Medium Urgency	Activates in a medium state of emergency where response time is important
Automated Alert 3	High Urgency	Activates in high states of urgency where response time is critical
Automated Alert 4	2 modalities	In the case that only 2 modalities can be supported, only visual and tactile actuators are active
User Activated	Emergency	Activated by the user releasing a pull tab on the chest. Activated only in

Alert 1		rare cases of emergency where immediate attention is needed.
User Activated Alert 2	Attention Getter	Activated by the user in non-urgent situations by pushing a button on the left arm.



(a) Jacket front and side, alarms off



(b) Alarms active

**Figure 3. Garment prototype.**

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# Flutter

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**Abstract—** Hearing is one of the fundamental sensory inputs that permits us to respond to and navigate our surrounding environment. Without intact hearing, the inability to detect warning signals such as fire alarms, police sirens, and honking horns can place individuals with impaired hearing at a significant disadvantage while navigating their environment. Common assistive technologies such as hearing aids, cochlear implants, and hearing dogs provide a means for individuals to respond to their environment more intuitively, however, the situation or context can render these aids inappropriate. Developing a wearable system to tactilely relay information can empower an individual with a hearing impairment to move confidently throughout their environment without the extraneous need of having small pieces of technology that can easily get lost (hearing aid) or the need of a canine escort (supervision can increase cognitive demand and requires one hand to maintain control of the dog). Flutter integrates function and fashion to relay information about the auditory environment for a holistic feedback system. If a sudden or loud alert is detected, such as the honk of a horn or the blare of a fire truck, the leaflets of the garment will begin to flutter in the direction and with the intensity of the signal for haptic notification.

**Keywords** –haptic; hearing impairment; collaborative robotics.

## I. INTRODUCTION

Approximately 36 million Americans suffer from a varying degree of hearing impairment [1]. The sense of hearing is considered essential for performing tasks such as navigating one's environment, responding to warnings, cries, and alarms, and basic interpersonal communication. While a plethora of assistive technologies exist to supplement this disparity, hearing aids still prove to be the number one rejected assistive technology on the market as only 20% of the hearing impaired population are willing to wear one [2]. Other common aids include cochlear implants, hearing dogs, and visual or vibrotactile alerts. However, for a number of individuals the technology itself may be unappealing due to social stigma, may be cumbersome or non-portable, or in the case of the hearing dogs, may be an added responsibility and unsuitable for many situational contexts.

### A. Haptic Feedback: Unmapped Territory

Even the most successful hearing aids can only achieve 6-8 frequency channels of information across the spectral range, making fine grain speech resolution difficult for the user [3].

Flutter is able to achieve the same level of frequency capture, and can serve as a less invasive method of information communication for the hearing impaired. This garment lends to the potential for users to adapt to a new method of hearing. By internalizing the vibrotactile feedback, the user can in essence, learn how to hear in a new way. Flutter serves as an elegant medium to internalize the external environment.

## II. Design Concept

Flutter was designed to assist those with hearing impairments with the many challenges that they face when navigating one's external environment. Such challenges include being able to effectively detect warning notification systems such as fire alarms, the blare of fire truck sirens, or the horn of an on-coming car. Typical assistive devices such as alarm beepers or hearing dogs are programmed/trained to respond to common alerts in the home, such as a fire alarm, the buzzer of a microwave, or an alarm clock. Once an individual leaves the home, the personal beeper becomes unserviceable, and the dog is no longer responding to an accustomed array of alerts. Instead, in an external environment



Figure 1. Flutter (front view)



canines react natively to their surroundings and the user is trained to respond based on the dogs actions. Designed to be worn in public, Flutter picks up where many home tuned alert systems and hearing dogs leave off.

In the United States, all public establishments are required to permit hearing dogs. However, this does not translate globally, and can at times be inconvenient when extensive traveling is involved. By making Flutter a hands free wearable system, it can more seamlessly remain with the user and reliably communication information in a consistent manner. Flutter is a dedicated system that can pick up localized auditory cues that it then translates into vibrotactile feedback for the user to respond to intuitively. Flutter uses a natural mapping to keep the feedback consistent with the directionality of the auditory signal, giving the user an accurate representation of the sound environment. The haptic feedback materializes through vacillating leaflets on the front exterior of the garment (designed to look like mere ornamentation when at rest), as well as embedded vibrotactile motors in the back of the garment.

### III. THE FLUTTER TECHNOLOGY

Flutter relies on a coordinated network of microphones, microcontrollers, and vibrotactile motors that work together to detect and relay auditory information throughout the garment. Miniature microphones instrumented within the garment send auditory information to the microcontrollers which amplify the signal and attempt either a time-of-flight (TOF) differential or sound intensity differential to detect the directionality and proximity of the respective noise. The microcontrollers then interpret the signal and instruct the appropriate vibrotactile motors to actuate. Each microcontroller can be thought of as a miniature robot that extracts sound from the environment, communicates with its neighboring robot, and responds in a coordinated fashion to deliver tactile feedback at the localized point of the auditory signal. The shirt is adorned with decorative leaflets that, when at rest, appear to be just ornamentation. However, the leaf network actually responds to the auditory cue by starting to flutter (using vibration motors sized 6 mm by 10 mm) in the direction of the sound. The fluttering leaflets will move with the sound as the auditory signal moves in space. For rear auditory feedback, coin vibration motors (8 mm diameter) are instrumented throughout the back of the shirt and actuate against the skin when a posterior sound is detected, indicating the direction and proximity of the auditory alert. Thus, vibrotactile feedback on the upper right shoulder blade indicates an alarm coming from the rear right. The louder the signal - the more intense the vibration.

#### B. Design Execution

Flutter uses embedded electronic technology consisting of microphones, microcontrollers, and vibrotactile motors. Operational amplifiers coupled with microcontrollers affixed to small printed circuit boards integrated into the garment perform the acoustical analysis and signal processing. Each circuit board is responsible for actuation of up to four vibration motors, as well as processing the signal from a single



Figure 2. Flutter (close view)

microphone. The signal from the microphone is first amplified and filtered using a gain stage before being fed directly into an analog-to-digital converter port of the microcontroller. The microcontroller is continually sampling the data stream as it fills a buffer. Once the buffer has been loaded the microcontroller performs a fast Fourier transform (FFT) on the sample and begins to load another sample. The FFT transforms the auditory signal from the time domain to the frequency domain which permits identifying the signature of the signals of interest. The microcontrollers also convolve the auditory samples of neighbor microcontrollers to attempt TOF analysis for localizing the acoustic signal in space. Once the microcontroller network selects the proper motors for actuation, the microcontroller(s) responsible for those motors will be notified to actuate, providing the haptic feedback to the user. The network sampling rate is sufficient to permit the fluttering leaflets to move with the sound as the auditory signal moves in space.

### ACKNOWLEDGMENT

Special acknowledgement goes to the coordinated efforts of members of the University of Colorado - Boulder's, Department of Computer Science Robotics Lab, Craft Technology Group, and Wellness Innovation and Interaction Lab. This highly interdisciplinary project was the result of dedicated collaboration and iteration, and would not have been feasible without such a cross section of skills and talent.

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# **ISWC 2012**

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# Wearable EEG monitoring to estimate workload

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## 1. Introduction

Working life is undergoing considerable and continuous change. The increased use of information and communication technology and changes in employment patterns represent new challenges to mental health and well-being. Work-related stress is experienced when the demands of the work environment exceed the person's ability to cope with or control them [1]. Stress can lead to psychological or sleeping disorders. If the stress response continues over a longer period, or if it is particularly intense, this may result in absence from work, can cause mental illness (anxiety, depression, sleep disorders) and contribute to health problems. In the functional state of the brain has been studied and it has been shown that mental workload, if increased, can lead to stress and depression.

Many researchers have investigated physiological [2] measures such as heart rate variability, galvanic skin response and electroencephalography (EEG), to predict workload. Investigation based on EEG can further benefit from the advances in the field of wearable EEG devices that enable to take the technology out of the lab and in to the daily life. Therefore it is still an open challenge to link mental workload to brain activity with wearable EEG, which can unobtrusively monitor brain activity. The goal of this project is to develop methods for ambulatory long-term measurements of brain activity and proof of concept application prototypes.

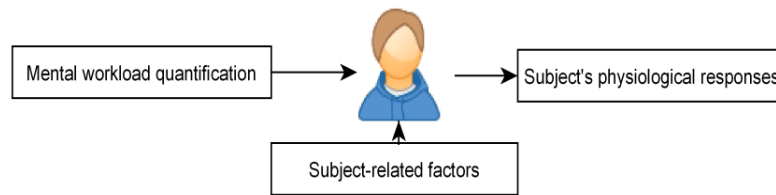
## 2. Related work

Work-related stress monitoring is still in exploratory stage. Stress is known to activate the sympathetic

nervous system. Previously published studies have reported effect of mental stress on changes in various physiological parameters, e.g. heart rate, blood pressure, skin conductance, skin temperature. The analysis of mental stress has focus mainly on the effects of stress on the cardiovascular system [3]. In [4] an attempt to correlate electromyography data to mental stress can be found. A number of studies dealt with the assessment of mental workload from electroencephalography (EEG) data when the subject is performing specific mental tasks and under constrained laboratory conditions [5]. It still remains an open challenge to combine the everyday office scenario setting with EEG measurements in order to assess mental workload.

Technological advances have led to the first wearable EEG devices and several manufacturing companies have also developed a variety of software applications to assess task engagement and cognitive performance while the subject performs specific tasks. Leveraging these technological advances, the goal of this project is to develop methods for ambulatory long-term measurements of brain activity and proof of concept application prototypes. Special focus is on context recognition methods that fuse information on user's mental status with information obtained from more traditional context recognition sensors. The wearable sensor system will be developed and evaluated regarding application design and usability in studies.

## 3. Proposed Approach and Requirements



**Figure 1. The proposed concept. The approach to link mental workload to physiological responses can be divided into three tasks: mental workload qualification (e.g. subject's computer activity), consideration of subject-related factors (e.g. self-report of perceived workload) and measurement of the subject's physiological responses.**

In order to link the measured physiological signals with the mental workload and the perceived mental strain in an office environment, we adapt the approach shown in Fig1. The approach can be divided in three tasks: 1) Quantifying mental load, so that the amount of mental work can be objectively measured, 2) Obtaining the baseline and perceived mental strain through self-reports from the subject and 3) Measuring the subject's physiological responses related to mental strain.

The first task could benefit at the beginning from the use of controlled cognitive mental exercises that have been used in previous studies. The ultimate goal is to measure different activities that are related to office work. For example, knowing the activity on the subject's personal computer, the rate of incoming emails or the speed of typing can provide information on the instantaneous workload of the subject. There are a number of commercial time tracking tools for computer related work that can provide relevant information for the first task. The self-reports, on the other hand, will serve to identify the conditions under which the subject is working and the perceived mental stress, which will provide us with a reference for the experiment. A number of standardized questionnaires exist to assess mental stress, like the NASA Task Load Index. Finally, the last task is to obtain measurements from the physiological signals that we want to examine in correlation to mental stress. The first physiological signal to be measured will be the electroencephalogram (EEG) by using a wearable EEG device. Other wearable, physiological, motion and environmental sensors can be added, to add other physiological and contextual information in the assessment of mental state.

Our first objective is to test the feasibility of such a wearable system. Once proven, the next goal is to assess the mental state of a specific person, taking into

consideration that the responses to stress may differ in the same person. If the assessment can be successfully achieved, our higher goal is to investigate whether an objective index of a person's mental state can be formulated.

#### 4. Future work

In this paper we have described our approach towards mental state recognition in the office environment. Starting from defining the system components and their requirements, we will continue by testing it in office settings. We aim at proving the system's feasibility and evaluating its ability to detect mental state for a given person. Having developed a first proof of concept, the evaluation can continue with the evaluation of the systems on different subjects.

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# Designing for Societal and Commercial Adoption of Smart Textile Applications

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## Abstract

*With this research-through-design process we aim to provide methods that will increase the chance of societal and commercial adoption of smart textile applications for eldercare and rehabilitation. These methods will show how designers can guide the collaboration between companies from the textile and technology industry, and eldercare service providers. We will illustrate the research goal with examples from the Smart Textile Services CRISP project and will discuss further plans of this PhD research.*

## 1. Introduction

Within the field of wearable computing we focus on smart textiles: the integration of technology, such as computing, sensors and actuators in the textile itself. Technological challenges such as power use, heat dissipation and networking have always been an important issue in the field of wearable computing [1]. As the field of smart textiles is maturing, non-technological challenges related to societal and commercial adoption are becoming increasingly important to focus on [2]. Within the Smart Textile Services project of the Dutch Creative Industry Scientific Program (CRISP) [3] we are investigating how the creative industry can contribute to tackle these societal and commercial adoption challenges.

Societal adoption of new technologies changes the way people behave and experience the world. For example, the adoption of the mobile phone made the way we manage our social relations more flexible [4]. Until now the developments in the field of smart textiles has been relying on explorations, while this now needs to change to a more systematic approach [5]. For smart textiles to be adopted by society it is necessary to develop design methodologies which fuse research and consumer insights [2]. We will focus specifically on developing smart textile applications for the domain of eldercare and rehabilitation. In the field of wearable computing healthcare and eldercare has been a topic of interest. For example for the assistance of nursing staff [6], support for people with

dementia [7] and neonatal monitoring [8]. Wearable computing is beneficial for this domain as it can help the user, the caretaker and other stakeholders in the care process to perform their tasks more efficiently, while also maintaining the intimacy that is needed in this field of application. The second challenge, commercial adoption, is about helping industries to collaborate in such a way that they are able to take new smart textile applications to the market. The paradigm of open innovation [9] learns us that in a complicated field as smart textiles companies need to transfer knowledge between the domains of textile, technology and eldercare services. This collaboration is not natural, because of differences in process, company culture and language. It is the challenge for companies to find enough common ground and shared ownership within the development process [10].

We are exploring societal and commercial adoption challenges by applying a research-through-design approach. This approach can be seen as an iterative transaction between design and research in which knowledge is generated through cycles of designing, building, and experimentally testing experiential prototypes in real life settings [11]. The consequence of this approach is a first person perspective on the design process. Designers perceive themselves as the point of view from which they perceive systems and products: we are a part of our designs [12].

## 2. Research goal

Since we are aiming to provide insight in how the creative industry can help in tackling the challenges of societal and commercial adoption we are zooming in on the role of the designer. This designer is not a traditional designer whose responsibility it is to style the end product or an industrial designer who is skilled in engineering. Instead, this designer should be considered more as an “interpreter”: a person with basic knowledge of the domains of textile, technology and eldercare services. Because of the collaborative nature of smart textiles, such as person can be the link between the domains and society, the person who can help to guide the applications towards societal and

commercial adoption. The goal of my research is to investigate *how designers can guide the multi-stakeholder collaboration process towards societal and commercial adoption of smart textile services for elderly care and rehabilitation*. The contribution of my work for the wearable computing community will not be found in the technological advancements. In fact, this is the part where I have a lot to learn from this community. I hope that my research approach and research questions can offer a different perspective on the process of developing wearable technologies and will provoke discussion about the societal and commercial adoption of applications within this field.

My starting point was in exploring the commercial adoption challenge by bridging and finding common ground between the companies. This was done collaboratively with textile and technology companies, and an eldercare service provider by exchanging expertise and skills in workshops [10]. These activities created the opportunity for the companies to find each other and possibilities for collaboration within the field of eldercare, and more specifically rehabilitation. For the societal adoption challenge my goal was to explore how designers can negotiate between their own design vision, end-user requirements and goals of other stakeholders, and accordingly set the frame for the design process. By providing prototypes of initial ideas the companies were able to articulate what they value about the idea. For example, I developed the audio fabric shown in Figure 1 as an example of how sound and smart textile can be combined to make physical movement exercises fun. An engineering company recognized the pressure sensitive capabilities of the fabric that they can use in curved surfaces. A producer of non-woven fabrics saw new possibilities of their semi-conductive materials, and the eldercare service provider reacted on how and when they wanted to trigger physical movement.

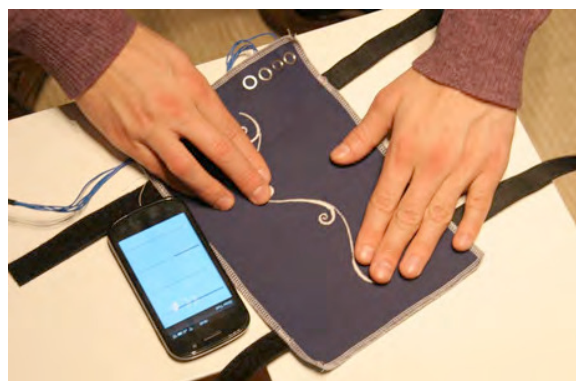


Figure 1 Audio fabric to stimulate rehabilitation exercises with music.

### 3. Next steps

To explore societal and commercial challenges I am continuing my research-through-design process on three levels: collaboration, context and tools. The group of collaboration partners is composed from an electronics engineering company, a design agency specialized in new business development, a textile company with experience in medical textiles, an eldercare service provider and an creative platform with experience in testing new products in the care domain. With a group of therapists and caregivers we are iterating through research-through-design phases to design, build and test new applications in the societal context. To increase the quantity of prototypes, to further integrate technology into fabrics and to tailor the applications to the end-users we are investing in a computerized knitting machine.

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# Application for the Doctoral Consortium at ISWC 2012

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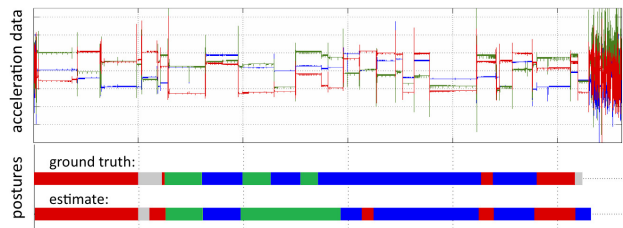
## Abstract

*Long-term monitoring for activity recognition gives the possibility to derive characteristics from the data such as daily activity rhythms, certain quality measures for the performed activity or detect abnormalities in the data. Such monitoring is applicable whenever patients have to be monitored who are not able to keep log of their activities, e.g. patients that are living in their private home. The goal of this work is to identify features in long-term data and assess their value in regard to rhythmic, quality and meaning for each activity performed.*

## 1 Activity Rhythms

The PhD thesis explores the possibilities of detecting key activities with a single sensor. The sensor is worn at the dominant wrist and records inertial data over a long time-span. Long-term monitoring is challenging, since the monitoring system has to be easy to deploy, should meet privacy issues and generate accurate data. Some challenges were already met in [1], where a deployable system is presented and privacy concerns are addressed.

This research is focusing on finding daily rhythms, similar as described in [2] and [7], where in both studies activities are being modelled in order to identify similarities or differences in the daily routine. In everyones daily routine a very important activity is sleep. Since most phenomena happening during sleep are still unknown, research in this field needs to be conducted in more detail. Traditionally, sleep is examined in a sleeping lab where the patient has to spend a few days and is being attached with over 20, mostly hard-wired sensors while sleeping. Therefore, a new set-up is desirable, which would take place not in a sleeping lab, but at a users home, monitoring his or her sleeping activities in the usual environment. Working together with sleep lab specialists is therefore necessary, which is why a collaboration with several local sleeping labs is in progress.



**Figure 1.** Accelerometer readings from a wrist-worn device (top) are used to estimate sleeping postures (bottom), for each night.

## 2 Previous Work and Own Results

With regard to sleep, many products are available that give information on how a user slept. Yet, these products are either restricted to sleep only or are uncomfortable to wear. An example for the latter represents the Zeo<sup>1</sup>, where the worn sensing device is located around the head, measuring the brains electrical activity. Sleeping trends gathered by the headband are then displayed to the user. In [3] a different approach is presented to display sleeping trends by using sleeping postures, which are being detected by a KNN (K-Nearest-Neighbour) classifier with an accuracy of 88%. The postures are color-coded and examined over a longer time-span, leading to a rhythm model with similar nights visible immediately. A person has his/her favourite postures per night, meaning that whenever an exceptional night occurred, this is visible in the model. From that, not only an abnormal night is being detected, but a quality measure for sleep is discovered through postures. Figure 1 displays the sensor data of one night that was recorded and the postures (ground truth and estimated postures) corresponding to the data. This work has been presented at ISWC 2010 in Seoul, Korea.

Monitoring people in their most private environment (the bedroom) and gathering medical data often raises the question of privacy. Therefore, the possibilities of recording sen-

<sup>1</sup>myZeo: <http://www.myezo.com>, last access 03/2012

sible data have been explored in [1], resulting in a privacy policy that meets the standards for such data recordings in Germany. In the course of that research, a recording environment has been established, which consists of an infrared camera that is used to record the ground truth for sleeping events.

Different modalities are crucial to consider when modelling a person's night: the amount of motion, duration of sleep and the falling asleep and wake up times. Interestingly, these modalities tell us a lot about our sleeping behaviour: the amount of motion is a quality measure that when being elevated, indicates that a night was qualitatively poor, which can also be observed when a person slept unusually less. All these information are used as a prior to model a person's night, leading to a classifier that can distinguish between regular and irregular nights. This work was presented at AmI 2011 in Amsterdam, Netherlands [4].

Recently, results from a large-scale study were presented at IHI 2012 in Miami, Florida [5]. Here, data from 8 different subjects (including 2 subject suffering from sleeping disorders) were recorded with a deployable system, which consists of the infrared camera and the wrist-worn sensor. The subjects nights have been extracted by a HMM (Hidden Markov Model) classifier with the accuracy of 95%. The non-movement data of sleep was then modelled into a color to visualize outliers in sleeping trends. Additionally, myoclonic twitches have been researched, which are sporadic muscle contractions by the extremities. These twitches are an indicator for REM (the deep sleep phase) which can be detected accurately only with a sleeping lab set-up. Precision and recall of 73% and 66% respectively have been achieved for the twitch detection, which are very promising results.

### 3 Future Directions

Since the sensor was mostly deployed among healthy persons and lots of data from normal sleep has been recorded, the possibilities of detecting abnormal sleep need to be investigated. In a current collaboration with a local sleeping lab, sensors have been given out to patients that have to spend the night in the sleeping lab. Additionally to the sensor data, the patients reviewed data that was recorded with the sleeping lab equipment will be received, which consists of the doctors diagnose, including sleep phases and sleep postures. With this absolute ground truth, previous findings can be sustained and new sleep characteristics are expected to be found by solely using the wrist-worn sensor.

Even sleep being an interesting topic, finding rhythm data not only in sleep itself, but also in other activities is desired. The first step towards modelling daily rhythms of all activities is to establish a rule on when activities occur. Inspired by the work of Partridge et al. [6], activities from the

common German resident are being analysed. For this, the German time-use database is used, which was established by the national statistics agency, containing daily activities of over 12 000 participants who kept diaries for three days each. A first analysis of the time-use data indicates which features are useful for activity recognition, e.g. previous performed activity or current location of the activity. Features are also being combined to boost the recognition rate for activities. The performance of activity recognition by solely using information from the time-use database will be compared to a system which uses the time-use database as a prior in order to detect activities on inertial data. With such a set-up, an activity model is being established which can be used for further studies in activity recognition.

### 4 Expectations from ISWC DC

ISWC has a very strong history in activity recognition and gives the opportunity to receive feedback from and exchange ideas on these topics with fellow researchers.

Discussions with other PhD students and specialists in the field of activity recognition and wearable computing are being expected. This way, the possibility of establishing new acquaintances is given which might lead to future projects that are being researched in a collaboration.

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# Using Wearable Technology to Make Fashion Accessible

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## Abstract

*Fashion represents a visual language that often leaves people with vision impairments out of the conversation. From the basic information of garment color to more complex entities of outfit coordination, many aspects of clothing are inaccessible for those who are blind and low vision. With advances in wireless tagging technology and smartphones, we are working towards replacing the traditional clothing tag with washable smart tags that provide a wealth of information in an accessible manner. These smart tags can not only render the basic information currently found on clothing tags accessible, but also be used to make recommendations and inform clothing decisions, making them universally beneficial for those with and without vision impairments.*

## 1. Introduction

Clothing is a visual form of communication, thus making it inaccessible for people with vision impairments [2,5]. We began our investigation with a diary study with eight visually impaired female participants (ages 21 to 73, average 37.25) to explore fashion from their point-of-view (only females responded to the study announcement) [4]. Our participants' vision abilities varied including low vision, loss of vision at birth, and loss of vision later in life. Even with the diversity of participants we found there are many common accessibility barriers, primarily objective (e.g., knowing a garment's color or care instructions) and subjective (e.g., knowing if garments coordinate or are appropriate for an occasion).

Our participants expressed feeling at a disadvantage because most everyone they encounter can see (and make judgments about) their fashion choices but they do not have a way to learn the norms and extremes of fashion. They relied on considerable assistance from people who are sighted, which can be frustrating since someone may not always be available. Also, relying on the insight of others reduces the opportunity for true self-expression as their opinions have an undeniable influence.

Our participants stated they were not aware of any assistive technologies for making clothing decisions and expressed a strong desire to have something available. This led us to explore existing technology solutions and we conducted an online survey to ensure we were on the right track. Twenty-two adults (11 female) completed the survey, which focused on how participants make clothing decisions and their interest in futuristic technologies. Seven men and two women reported that they had some form of vision impairment. We recruited individuals with and without disabilities to keep universally accessible design in mind [7,9]. We learned that clothing decisions are often made collaboratively and that people would be interested in having assistance with coordinating items in their wardrobe and knowing the latest fashion trends. With all of these findings we believe a smart tag solution will fill a gap in the current technology landscape.

## 2. Related Work

Many new assistive technologies for those with vision impairments are being embedded in clothes including jackets, shoes, and glasses to assist with object detection [1,3,10]. While these technologies have many advantages they are simply using clothes as the shell for the technology, not addressing fashion needs or as fashion targeted for those with vision impairments.

With advances in wireless technologies such as RFID, Bluetooth®, and ZigBee®, it is possible to create low-cost solutions with wearable clothing tags that store objective information such as the color, size, and care instructions. Once accessed, this information can then be used to make recommendations, provide instructions, or inform decisions. Other researchers have implemented such smart closet solutions and included algorithms to assist with coordinating outfits but we have identified some limitations with these technologies [6,11]. First, the interactions are limited to closet hangers. Also, the solutions are not accessible for people with vision impairments as the output is displayed as images on a computer screen. There is no mention of those with vision impairments (or any other disability) in the design

considerations and the solutions presented do not appear to have these users in mind. Lastly, the solutions are not streamlined, as they require sitting at a computer to access information.

In 2006 a proof-of-concept device called “Closet Buddy” was created with a similar goal of being accessible for people with vision impairments [8]. This system had many hardware limitations that made it difficult to use and sustain. For instance, relying on prerecorded messages rather than a screen reader due to limited processing power in the PDA. A streamlined, real-time solution is possible using current devices and though technology continues to evolve, smartphones have revolutionized how we access information and we believe are the key to a sustainable and usable system.

### 3. Current and Future Work

Clothing tags are inaccessible and dated – they itch or fade, are written in extremely small print that is difficult for those who even need reading glasses to see (let alone someone with a vision impairment), and the information they convey is limited. We propose the use of smart tags as the new clothing tag. Our vision goes beyond past work that instruments dressing rooms, such as The Magic Mirror [13], by making a mobile solution that works virtually anywhere. We feel that small, passive, washable tags sewn in a garment offer many solutions to make clothing accessible and are exploring new applications.

We are currently developing a prototype to link basic information (color, pattern, fabric, size, and care instructions) to an RFID tag. This information will be read using an Apple iPhone, which is pervasive in the Blind community [12]. When a tag is scanned, the information will be rendered using both a spoken and visual output to ensure universal design. We will pilot our system in the wild with users of varying visual abilities. We hypothesize this solution will have a great impact for those with vision impairments but also may be beneficial to people who are sighted including those who get dressed in the dark (perhaps to not awaken significant others and family members). Understanding not everyone has an iPhone we will also explore other smartphones as well as cost-effective independent reading devices. We will also explore adding more information to the tags including clothing style and price. This will further assist users with vision impairments while shopping and choosing an outfit.

Building on this implementation, we will explore how we can make other people’s fashion accessible to those with visual impairments. We envision a reading device can be used to gather information about someone nearby and make the information one would see visually (such as

fabric color and clothing style, but not size or care instructions) accessible. In addition to helping people understand fashion trends and personal expression it can also serve the practical purpose of identifying uniforms such as policemen. We are also interested in building a system to both read and store information about what others are wearing to inform purchasing decisions.

Lastly, we are interested in building on past work to develop algorithms that make suggestions for coordinating garments. This was a top request in our online survey and would assist many users in getting the most out of their wardrobe.

Ultimately these smart tags can become a new pervasive technology that significantly levels the playing field for those with vision impairments and adds new features and functions for everyone’s benefit.

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# Measuring Garment Movements in Wearable Sensing

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## Abstract

Electronic textile (e-textile) is a promising technology to develop novel methods for imperceptible body monitoring. Body monitoring devices are highly used in a large variety of application, from health care to sports. The noise introduced into the signal of a wearable sensor due to slippage or movement of the garment housing is frequently acknowledged as an important barrier to successful long-term ambulatory monitoring. Garment movement as a noise source has not been studied in depth. In the investigation presented here, I use controlled experimental garments and a humanoid robot to precisely evaluate the movement of garments with specific parameters over the body surface. Specifically, I investigate two sources of error: repetitive garment movement error due to garment ease (difference in circumference between body and garment dimensions), and repetitive garment movement error due to differences in textile properties (weight variations of an identical fiber content and weave structure). Because the problem here is unexplored, my approach takes an exploratory direction. I find some early observations about the influence of garment size and textile composition. A good deal of further research is required to better characterize these important variables.

## Introduction

Garment-integrated sensors may be among the most pervasively acceptable or comfortable sensors, yet they often experience the most noise due to comfort variables that may be directly at odds with variables that optimize sensor performance. Discovery of the noise variables of wearable sensor measurements is crucial to overcoming this obstacle. The error itself is influenced by the movement of the garment over the body surface, but may also be corrupted by other external factors, such as donning and doffing, that are independent from the garment properties. Dunne [1], underlines the significant effect of garment movement on sensor performance, identifying the major variable of garment slippage and re-positioning as the error source to analyze in more detailed future research.

Perceptibility of the user is also a crucial aspect to consider, because for instance a user with an odd-looking, bulky, or burdensome device may compromise his daily life, degrading quality and therefore reliability of the data that for example are being collected for medical applications, such as body pressure monitoring or ECG signal analysis. Costa et al. [2], shows that an uncomfortable or attention-demanding device can change the behavior of a patient, with the result that the collected data does not reflect the normal lifestyle. Thus, unawareness of the user wearing an e-textile garment has a strong impact in the quality of the collected data.

## Experiment Setup

The experiment setup presented here is the one adopted in our earlier works [3, 4, 5]. The objective of our experiments is to analyze the garment movement of a pair of pants during a walk/run. The test garments were all constructed using a common drafting procedure for men's trousers, over 5 different sizes: 1" increase at waist and hip circumference for each successive size; this increment was tapered down to a 1/4" circumference increase at the ankle to maintain the garment style. 5 fabrics with different textile properties were tested.

We utilize an IR motion capture system based on retro-reflective passive markers which collects position samples on a 3D coordinate space (X,Y,Z), with nominal frequency of 60Hz. Two parallel experiments are conducted: 20 markers are strategically placed on top of pants worn by a mannequin constitute of an electronic skeleton that is able to reproduce a human run; using the same marker location but on a skin tight suit, a spatial reference for each marker, at each time instant, is defined.

## Experimental Approach

Data analysis is done per gait cycle. The periodicity property allows us to extract all gait cycles available in the experiment, along X, Y, and Z coordinates. The approach used to first extract and then align the gait cycles of the skin tight suit and pants experiments, overlaps samples over the same relative position within the gait cycle of body and pants cycles, where the reference position for defining the cycles is detected

corresponding to the peak value of a reference marker. The sample relative position in the gait cycle is easily determined by considering the fact that we have a constant sampling rate, therefore equally spaced samples, and that the reference marker used for the alignment is only affected by small precision error, due to the camera capture capabilities limitation.

Once that the gait cycles of duration  $T$  are determined and correctly aligned, the Euclidean distance mean  $d_{e_k}(t)$ , later called as Euclidean error, for each Marker  $k \in K$  on pants  $(x_{p_k}(t), y_{p_k}(t), z_{p_k}(t))$ , and on body  $(x_{b_k}(t), y_{b_k}(t), z_{b_k}(t))$ , is computed at each time instant  $t \in T$  by averaging overall cycles,

$$(1) \quad d_{e_k}(t) = E_{cycles} \left[ \sqrt{(x_{p_k}(t) - x_{b_k}(t))^2 + (y_{p_k}(t) - y_{b_k}(t))^2 + (z_{p_k}(t) - z_{b_k}(t))^2} \right]$$

Formula (1) is a sample by sample average over all the gait cycles. We are interested in characterizing how the average Euclidean error is distributed in the different body locations. Thus we compute the average Euclidean error  $d_{e_k}$  over the gait cycle for each marker  $k \in K$ , by averaging again over all samples in the gait cycle, as shown in the following formula (2)

$$(2) \quad d_{e_k} = E_t[d_{e_k}(t)] \quad \text{for all } t \in T$$

## Results

After extracting positioning and drift error from the marker traces [5], we were able to evaluate movement error alone.

### I. Movement Error

Analysis of all 20 markers for 5 sizes of 5 different fabrics yielded unwieldy and noisy results. To simplify this analysis, markers were grouped by vertical levels (i.e., 2-6 waist level, 7-11 hip level, 12-14 thigh level, 15-17 calf level, 18-20 ankle level) according to their body location, and Euclidean distances were averaged over different fabrics of the same size. We have found a repeated pattern, shown in the following Figure 1.

Increasing the sizes, we notice that the Euclidean distance between same levels on skin tight suit and pants increases almost linearly, for all levels. An analysis by level for each of the fabrics allows finding consistent pattern between sizes, with the larger sizes that show greater ease.

These results are still general and do not reflect the variability of the entire gait cycle. We believe the approach adopted may be a promising direction for future investigation looking more closely at the “remaining” noise after that positioning and drift error are taken out.

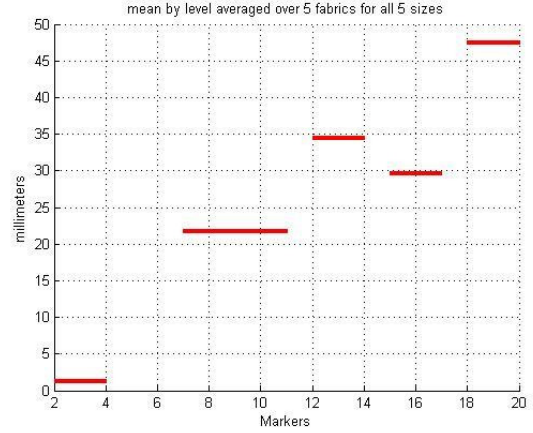


Fig 1. Average by level over 5 different fabrics for all 5 sizes (markers 5 and 6 were corrupted)

## Conclusion & Future Direction

The mocap data collected and analyzed using the method presented above are laboratory data. Even the instrumentation and method adopted are confined to an experimental setup. We are currently developing an alternative approach based on stretch sensing for translating and comparing the mocap data with real sensors data. The idea is to organize the stretch sensors in a regular structure, such as a grid, and then correlate the information given by each sensor in order to evaluate the entity of the garment movement.

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# Sensing Emotional State of Mobile Users for Improving Mobile Social Interaction

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## Abstract

*Emotional state of people affects the quality of their social interaction. If your friend or colleague is angry at the time of interaction request, you can expect to have negative response from them. This research aims to provide methods for mobile device users to know how their friends feel right before the interaction. Previous emotion recognition methods use additional sensors to sense the emotions of people. In my research, I use typical on-device sensors to measure usage behaviors of a mobile device for emotion recognition. Information about the emotional states of mobile users will be used to develop new methods to facilitate mobile social interaction. This study will contribute to developing a general methodology for recognizing emotional states of mobile users from only the usage behavior of the device by using common sensors on mobile devices.*

## 1. Introduction

Any challenge experienced due to an obstacle in everyday life affects the quality of our interaction and might cause the elicitation of certain emotions. Emotions are reactions to the challenges and encompass complex expressions of which components are affective, physiological, behavioral and cognitive ones [1]. Emotional expressions are the implicit rules in human-human interaction and they support the communication by clarifying, stressing the message and confirming or disapproving the message using emotional expressions[2]. For instance, people can understand how a person reacts to what is said looking at the face of that person.

Mobile social interaction tools provide a communication medium with friends and are designed for improving users' social relationships. Although current mobile social interaction tools are able to support the sharing of message in different types, they do not allow you to know emotional state of your

friends right before the interaction. Learning emotional states of people that you want to communicate with can give you to best select how you would like to interact with them. For instance, if your friend is angry now, you may wait until they are happy for an interaction.

This study aims to improve mobile social interaction tools utilizing emotional state of mobile users. Also, users' concerns, and preferences to use that information with other people are other goals of the study. Following sections presents an overview about emotion recognition techniques and studies related to my research in the literature.

## 2. Related Work

Emotion recognition takes interest of a high number of researchers from several different fields including Human Computer Interaction (HCI). Current solutions in emotion recognition area mainly use the techniques that analyses facial expressions, voice[3], body and posture, and the change in physiological values in the body using wearable sensors[4]. Those methods are strictly tied to laboratory settings, as they require high computing power. Also, some of them require additional sensors attached to skin, which is not feasible to use in everyday experience. On the other hand, there are some studies in the field that analyses usage behavior of personal computer[5] and of mobile device to predict users' emotional states[6]. One of the advantages of those methods is that they do not require to use additional sensors or some embedded devices.

Mobile users' personality and mood affect the usage of mobile device. A recent study highlighted the difference between extrovert and introvert users[7]. That usage difference might be due to tendency of those users in the expressions of emotions. Also, moods, as being long-term emotional states, causes some differences in the usage patterns of mobile devices [8].

### 3. Methods

This research aims to develop methods to sense emotional states of mobile users and find useful ways to integrate the information in social interaction tools to support mobile users' social interaction. To achieve this task, I developed an approach that includes two basic steps:

*Step 1:* In this step, my aim is to develop a helpful method to predict the emotional states using on-device sensors. I chose Iphone as the mobile device. To recognize users' emotional context, I use accelerometer and gyroscope for movement and rotation analysis of usage behavior and touch sensor in the device for the analysis of finger-based selection and usage. I will perform feature extraction from sensor data to describe mobile device usage in an effective way. Also, to discriminate the location-based change in emotional state of the users, I will use GPS and Compass data. Emotions to be recognized are the ones universally acquired by every person. They are happy, sad, disgusting, anger, fear, surprise and neutral. Different machine learning algorithm will be tried to find best one for the emotion recognition task.

*Step 2:* In this step, I will develop new mobile social interaction methods that enable to learn enough information about how your friends feel now. To do this, I will analyze how much people are willing to share their emotional states with whom and to what degree. My aim is to provide some helpful information for the people who want to learn what their friends feel right before an interaction. So, it means that the interaction tool can also enable mobile users to control the form of sharing that personal information.

### 4. Results

I have already achieved to develop a mobile social interaction tool to collect emotion-tagged sensor data from mobile users. If the user feels a certain emotion, s/he self-reports the emotion. I continue to collect related data and perform some pre-analysis for feature extraction from the sensors data. I aim to complete Step 1 of the study in the next month (April 2012).

### 5. Contribution to Mobile HCI

This study will contribute to the knowledge in mobile HCI field from two sides: First, it includes the development of a new method for the recognition of emotional states of mobile users. This method will only use on-device sensors for the emotion recognition. Second, my study includes the implementation method of emotional state in mobile human computer interaction. I will develop new

methods that support emotional state sharing by taking the concerns of mobile users. So, my study will increase the understanding of mobile users' concerns on sharing emotion data.

### 6. Conclusion

In this paper, I presented the limitations of mobile social interaction methods and how emotional state of mobile users can improve the interaction. Also, I stated my general method to sense emotions of mobile users and integrating that information to mobile social interaction tools.

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# An Assistive Device for Shy Users in Face-to-Face Communication

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## Abstract

*Social situations can be difficult for shy people. Computer-mediated communication (CMC) technologies have been reported as helpful to shy users, but can also encourage withdrawal from face-to-face activities. The current research investigates the benefits of ubiquitous computing and slow technology by designing wearable computing devices which can be integrated into face-to-face activities and help increase comfort for shy users. Initial proof-of-concept prototypes have shown potential; testing with self-reported socially anxious subjects in a speed-dating environment resulted in 73% identifying the shirts as helpful to their meeting with strangers.*

## 1. Introduction

People have the need to belong and be socially accepted but those who suffer from shyness have an additional barrier to achieving this. Their lack of interpersonal skills (e.g. lack of conversational abilities) and intrapersonal (e.g. excessive self-consciousness) are constructed around a negative mental state – thinking and displaying oneself as socially incompetent when faced with situations requiring interaction with others. Therefore, they often leave a negative impression on others causing them to withdraw efforts in social interaction. This process forms the anxiety-inhibition cycle, which influences negative anticipation – fear of being rejected by others and being embarrassed by his/her own actions. [1]

### 1.1. Relevant works

Various forms of online CMC have been reported facilitating social relationships and as being more attractive to shy users due to their asynchronicity and reduced social cues. [2] However, this also allows for identity distortion, unrealistic expectations for relationship development, and withdrawal from face-to-face activities, making sociability in the real world harder for shy users. [3-4]

Context-aware, ubiquitous and wearable computing have been used to enhance user interaction with both the environment and other users. Previous research such as [5-8]

have been intended to facilitate face-to-face communication using some forms of wearable sensor network (WSN); however, none so far have combined context-aware systems and wearable social computing so as to support socially anxious and low interpersonal skilled users.

## 2. Approach

Social situations are dynamic and cognitive overloading in shy individuals is common due to excessive consciousness of being judged when coming into contact with others. The current research investigates ways of integrating some of the benefits of CMC into real-world social interaction while attempting to reduce this overloading, via the development of subtle and unobtrusive interfaces based on two design principles. One is calm technology: a design that engages user's attention at either central or the peripheral areas (the places where the human mind moves back and forth), at a time [9], thus may reduce information overwhelming in users' mental processes. Another is slow technology design that values reflective experience and promotes users' mental rest in rapid changes of environment. [10] In this, it shares similarities with Chalmers et al. [11]; in that both seek to understand problems relating to social anxiety in shy individuals using the advances of ubiquitous computing. However, the current research is set without demanding a conscious effort from users and aimed at reducing cognitive load and giving the user more background access to information. Specifically, the proposal here is to use a context-aware system together with a WSN environment, promising characteristics of ubiquitous computing that enable pervasive access to information. These may provide a useful technique to identify users' position and their 'contexts' e.g. alone or close to others in the network; and thus allow the system to transmit specific information to assist their conversation with other and reduce perhaps cognitive load according to the change in the 'context'.

## 3. Method

As a preliminary part of a research programme into techniques for adaptation of social behaviour in individuals

who self-report as socially anxious and consider themselves to have low social skills, four prototype T-shirts have been developed with unobtrusive interfaces (i.e. handshaking – a natural switch for controlling data exchange – and soft-circuit information display) and tested with socially anxious subjects.

Using CMC together with the essence of ubiquitous computing and wearable design – that naturally place technology in the user environment prior to the reflective experience of the user – we examine to what extent unobtrusive interface and unconventional use of technologies can enhance the effort of the user to improve social skills when faced with situations requiring interaction with others, and perhaps lead to more meaningful relationships in the real world.

### 3.1. Prototype

By leveraging online social network information (e.g. Facebook and LinkedIn) on clothing, the first version of prototype Icebreaker T-shirt is designed to be worn in real-world social events and make social contact easier. Radio frequency identification (RFID) technology is used as a control system for exchanging wearer's identity. When both shake hands, each shirt indicates their social relationships via a textile-based display (conductive thread and heat-sensitive paints), increasing a sense of familiarity and helping select new acquaintances (i.e. potential friends, partners, colleagues, participators) while maintaining the naturalness of the social interaction, as well as the comforting property of clothing.

### 3.2. First test

Using empirical method to compare user's behaviours we asked each of 11 testers (recruited with a customised questionnaire extracted from The Henderson/Zimbardo Shyness Questionnaire<sup>1</sup>) to participate in two speed-dating sessions: with and without the shirt. Both sessions were video recorded and used to evaluate the shirt's capability to increase comfort and generate topics for conversation. These results were used together with feedback given by the testers via a post-experiment questionnaire. 73% of testers reported that the shirt was helpful to meeting with strangers. One said: "*It gave a sense of having something in common to begin the conversation, something we both were interested in. Whereas when we didn't have the shirt, I felt we were only trying to make small talk.*"

## 4. Conclusion

Although the sample tested was small, and the technical justification process less sophisticated than that of the literatures reviewed, our first experiment underlines some problems and potentials of the chosen technologies for improving interpersonal skills of shy people. Taking the

current approach a step further, a more sophisticated experiment with shy users is currently being developed. The experiment is based on the same hypothesis but uses a second version of the T-shirt – replacing the handshaking method for exchanging users data with proximate distance enabled by mobile adhoc WSN positioning method. Thus the number of participants in each test group can be extended from two to four or larger. This implies a more realistic and professional social situation, rather than a speed-dating environment simulated in the previous experiment. Qualitative and quantitative considerations of test subjects' body language and conversation content, together with time spent before starting and during a conversation will inform the efficiency of the technology and technique. The outcome will be used with feedback given by subjects via questionnaire and compared with the data collected from the test of first version prototypes.

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# **The Embodied Feminine and the Sensory Self: Cross Disciplinary Practice Exploring the Feminine Ideal Through Sensors, Transposition, Metaphorical Tools, Embedded Technology, Composition and Performance**

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## **Abstract**

*This inquiry is a practice-led cross disciplinary exploration utilising sensors, embedded technology, wearables, and sound to produce multi-media installations, performances and compositions. The investigation will address social and theoretical discourse and debate on the feminine ideal, body image, identity and body modification. Drawing on Social Comparison Theory and Self Schema Theory, [5] [2a] the relationship between media exposure of a feminine ideal, embodiment and body image self-discrepancy, will be extracted and transposed through artistic practice. Using the metaphorical language associated with clothes and gesture, new meaning, processes, methods and original artifacts will be created by implementing existing digital media and music technology, with emergent technology; in particular fashion technology.*

*Through engaging and interacting with the works, participants, observers and practitioner(s) will gain a greater understanding of how the media, social and cultural issues can impact on the female body.*

## **1. Introduction**

Women are increasingly experiencing higher levels of distorted body image [2b], placing self worth in the context of their visual appearance. Femininity and the “self” is no longer embodied, Shields and Heineken [13] suggest that “[...] embodiment is achieved through striving for the ideal feminine form”. Bordo [8a] states “With the advent of movies and television rules for femininity have come to be culturally transmitted more and more through the deployment of standardised visual images”. Who sets these rules? As

suggested by Thesander [15a] the female ideal is ever changing to conform to prevailing contemporary views of women; it is a reflection of the culture we live in. “The corset, the bra, the roll-on-girdle, body building and cosmetic surgery are various forms of artifice used to alter the body” [15b]. As Bordo [8b] suggests, “The body may operate as a metaphor for culture”. In today’s society, it is no longer class which sets the female ideal, it is enforced by an artificial package of beauty, in the form of images of anorexic celebrities, perfectly molded and sculpted actresses and air brushed models. Embodiment has become embedded in the need to continuously transform to keep up with the current ideal, and the woman who strives to constantly change her identity to fit into the current ideal, loses her “self” [12].

Bolton suggests, “All clothes have social, psychological and physical functions” [3]. The types of clothes and the way in which they are worn provide meaning, that meaning is open to analysis and interpretation. Meaning and interpretation is not only through a garment, it can be seen through cultural and social association with a particular garment [1]. We judge people by their bodies and we change our behaviour and “learn our identity” [4a] through others reactions to our bodies. Bodies are for most of the time covered, concealed and sculpted with clothing, providing both a physical and psychological shield from external environmental elements, and social expectations and rules. The structure of a garment, and the way it fits on the body can impact on physical movement, this movement can be interpreted as gesture; it can be seen as a method of conscious and unconscious communication. Finkelstein [4b] suggests

that the clothed body is easier to read, therefore through clothing the body can be modified, and identity can be created or altered to suit a particular emotive state.

## 2. Related works

Works such as “Bubelle” [11] (The Blushing Dress) uses Philips Skin Probe technology to demonstrate how technology can be used in an emotive context. Similarly, integration of electronics, and smart fabrics are implemented in the “Intimacy” [7] project, which utilises foil materials to construct dresses. Through interaction, the dresses become transparent to reveal the body, the level of transparency dependent on how close an observer is to the dress. The “Printing Dress” [10] can also be seen to reflect on intimacy, social identity and communication, by enabling the wearers thoughts to be displayed on the dress. The work by Stead et al. titled “The Emotional Wardrobe” [14a] suggests that clothing can represent a range of human emotions through the use of integrated technology. They suggest that this extends to representation of the “self” by “[...] creating a narrative between the body, garment and society” [14b]. These examples demonstrate the possibilities of transposing emotion, intimacy and communication through metaphor and technology. In the context of the inquiry, a garment that forms part of an interactive experience, or a garment that changes aesthetically in harmony with the body, can be seen as a tool of communication. This tool can be used to metaphorically transpose the emotions held within that body. Emotions are influenced by external social factors, such as high-level exposure of a thin feminine ideal, and as studies show, this exposure and aspiration to attain a feminine ideal can account for body image discrepancy [9].

## 3. Methods

Traditional research methods and paradigms have historically informed research on practice [6a], with practice viewed as an object of study, not as a method of research. There are new and emerging approaches for the creative researcher, and the difference is that they lead research through practice [6b]. A hybrid methodology will be defined, enabling new methods and processes to take shape. The submitted exegesis will be supported with digital media, to reflect the processes and practical work undertaken.

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# Fashioning ‘Conspicuous Creation’ – a User-Centred Design Approach for Wearable Technologies

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## Abstract

*This study aims to evaluate whether placing the user conspicuously within an ‘Open design’ process can challenge ‘technology push’ mechanisms that currently marginalise users and potentially hinder mainstream adoption of Wearable Technologies (WT). It takes a socially deterministic approach to WT. Whereas WT has been hyped as the future of fashion; this research proposes fashion (when seen as an agent, representative of fluid social and aesthetic meaning) can, conversely, guide the design of WT. This paper briefly presents the contextual analysis that informed the research position; introduces the social concepts of ‘coolness’ and ‘connectedness’ being investigated; outlines the mix of primary research methods; and offers some initial supporting insights into the motivations of WT ‘user/makers’.*

## 1. Introduction

Despite the human user being the central component of a wearable system, to date, the user has rarely been visible within WT development. ‘Technology push’ into very niche or novelty application areas [7] has left users marginalised. There is growing recognition that a designed, need driven and only technology ‘anchored’ process [12] could deliver both socially and commercially meaningful WT. A new wave of enthusiasm for WT, triggered by smartphones and mobile apps, needs to be channelled towards mainstream acceptance and away from a valley of disillusionment. This will not only avoid commercial losses but safeguard research and development structures around future WT [9]. Consideration to the ‘why’ rather than the ‘how’ has been given to WT [2,8] but partial evidence indicates that aesthetic and consumer concerns are still given much less attention by the academic WT community [5]; thus generally overlooking the “social commentary inherent in radical fashion design” [13] which will impact consumer acceptance of WT.

## 2. Context Analysis

A thorough review of existing technologies and products suggested that, by not contextualising new WT tightly in terms of existing product genres, or narrow functional applications suggested by technical capabilities, some acceptance barriers could be surmounted. By considering perceived benefits that an ‘on-body system’ could deliver, a framework was derived based upon broader needs for: Body Performance, Safety & Protection, Mental Stimulation, and Communication.

Body adornments communicate as signs, e.g. indicating the sex or social status of the wearer, but the physical form has no inherent meaning. Recent considerations of fashion as material culture [11] have partially reclaimed agency for fashion objects and so fashion can be considered as “the outcome of a precarious marriage between the processes of creative authorship, technological production and cultural dissemination” [3]. This cultural diffusion occurs as we conspicuously consume [16] symbolic values in an attempt to furnish our personal identity [14] and thereby establish our social status. Digital communication tools increasingly enable us to construct and display personal identities and group affiliations online. Thus, exhibiting social ‘connectedness’ is a common communication role of both fashion and mobile internet applications.

Technology acceptance has generally been discussed in functional terms of ‘usefulness’ and ‘ease of use’ [6] but cultural tastes [1] are increasingly being considered legitimate factors. Visual design plays a significant role in increasing desirability or ‘coolness’; arguably contributing to the perceived ‘usefulness’ of a fashion object, given that one of its primary purposes is to increase the perceived social status of the wearer.

## 3. Conspicuous Creation

Leaving room for user adaptation and personalisation is an expanding movement within current design practice. ‘Open design’ facilitated over diffuse communities via

digital media, based upon shared knowledge and reciprocity [15], has the potential to more closely align products with individuals' needs and desires. Open design has fashion heritage within the home dressmaking tradition and there is a visible WT DIY community [4], suggesting fruitful mutual ground for exploring a user-centred design process, i.e. conspicuous creation.

#### 4. Research Goals & Methodology

The main and sub research questions are thus:

- Can putting the user at the centre of an open design process, facilitated by digital media and tools, improve the development of meaningful WT that are ripe for mainstream adoption?
- How relevant are user research outputs within an open design scenario where the designer/user overlaps?
- Can aspects of 'fashion' be deployed in an open design scenario to increase acceptance/desirability of the WT outcomes?
- What digital/social media tools can facilitate open design for a product category that crosses diverse disciplinary backgrounds?

Primary research is participatory: researcher is both facilitator and actor in the process. Based upon a co-design loop, research falls into three areas with associated research tools, connected by a pilot digital platform to enable interactions between users and designer/makers and free flow of design info. (Figure 1).

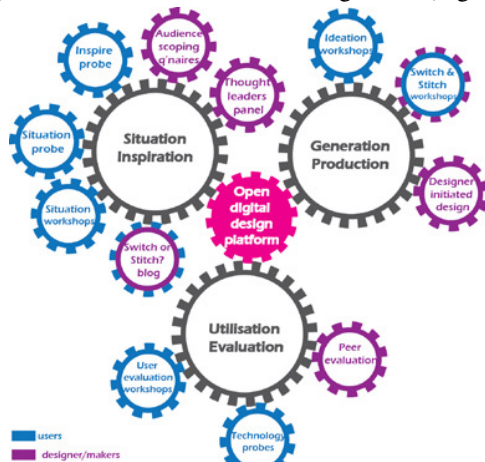


Figure 1. Switching & Stitching research methods

##### 4.1. Curiosity-kits – Example Research Method

To generate situational and inspirational input for open WT design, 'cultural probes' [10] are being deployed within two target user groups. Labelled 'curiosity-kits' to increase participant appeal, these ethnographically-based, task-filled tools are being custom designed to explore 'connectedness' and 'coolness' in mainstream contexts.

#### 5. Initial Insights

Surveys conducted with two WT maker groups revealed that motivations are equally about making for 'others' as for self-use. Most respondents used online resources for WT (predominantly for technical info and sourcing). A vast majority was positive towards developing WT via an online collaborative network but few were currently sharing their own projects in this manner. Findings support the hypothesis that providing research/design inspiration derived from user research will expand user/makers' design thinking to include broader needs/desires of 'others', potentially leading to more universal applications. They also suggest an opportunity space for aesthetic, human centred design knowledge within online design communities.

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# An Exploration of Multifunctional Woven Electronic Textiles by Design Practice

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## Abstract

*This paper presents a design research approach to exploring woven electronic textiles (e-textiles). Weaving methods are pushed and manipulated through the design of the textiles to fully exploit their potential and make modular multifunctional soft circuits through interactive complex one-piece structures on the loom.*

## 1. Introduction

Textiles are an ideal medium that can fit the transition of hard technology onto a more familiar soft substrate. E-textiles are an area of increasing interest in recent years due to their potential applications such as in wearable computing/ technology, responsive personal environments and other product end uses [1].

E-textiles are still an evolving area of development that aim to truly integrate electronics into and onto textiles; ultimately striving to fuse the two areas together to enable functioning e-textile products [2].

The developments of e-textiles have faced challenges to make them the ultimate desired flexible, robust and fully functional material [3]. Using a design approach to make woven e-textiles from a creative perspective may help realise alternative approaches.

## 2. Research Intentions

This research is an experimental enquiry of e-textiles materials development through hand woven design practice. The research adopts a design approach to constructing woven soft circuits. The design process follows a creative channel that attempts to give equal authenticity for the design and function; thus sees both as significant drivers producing innovative e-textiles. Drafting concepts through sketching, prototyping and circuit testing is vital to the end designs that are translated into complex woven structures.

Through integrating electronic components via the weaving process with the use of conductive yarns, responsive and adaptive woven e-textiles are produced, whilst pushing the boundaries of traditional weaving methods. The intention of the research also extends to enhancing and advancing the progression of e-textiles by more considered design through woven structural manipulations that seek to utilise their full potential. Modular formations have been employed as a design format for the e-textiles, as these will be used to configure multiple modules that can operate as independent units or in sequence in a modular system. The modular design provides adaptable and multifunctional textiles for a variety of end applications. The modules will be applied in workshops to enable participant engagement through exploring self-creation of e-textiles artefacts.

## 3. Methodology

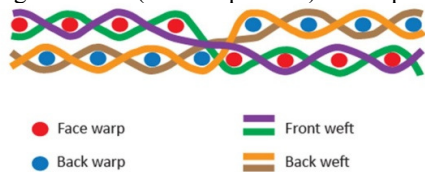
The weaving method forms the main making activity; however, the research is directed via a design process.

### 3.1. Weaving Process

Weaving is a form of constructed textiles where the process involves a warp (the vertical threads) and the interlacing of the weft (the horizontal threads). There are a vast number of established woven structures already used in woven textiles; each producing a different surface texture, aesthetic and tactile quality. The weaving processes implemented to make the e-textiles in this research are woven by hand on a 24 shaft Arm Patronic dobby loom. Each warp draft is exclusively designed so that it is suitable to execute the type of woven cloth required. The loom is set up by hand and weft yarns are selected depending upon the tactile quality needed. One method of manipulating the weaving process is to weave multilayer cloths simultaneously; when two layers are woven with this



technique, this is known as double cloth (Figure 1.). Using block draft threading plans and applying woven double cloth structures enables predetermined sections of the cloth to control and interact between layers, making isolated (woven pockets) or exposed areas.



**Figure 1. Double cloth woven structure illustrating point of interaction between layers**

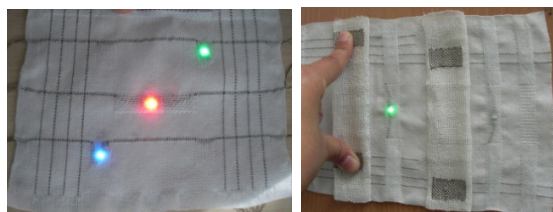
This method is heavily applied to much of the practical output to allow for better integration of electronic components.

### 3.2. Design Process for E-textiles

For this research, the making of the woven e-textiles follows a series of design process stages; from initial concept through to woven executions that are instigated and are crucial to the final outcomes. Inspirations for the form and function of the textiles are sought and used to translate through to the ideation process, that organize and formulate a breakdown of ideas to take forward into sketching and making paper/fabric prototypes. The prototypes help to envisage the physical forms of the textiles and the complexities of the electronics integration that are then circuit tested. Woven structures are designed and planned to suitably fit each part of the e-textile that are executed via the weaving process. The end samples are tested and analysed, where the results are also used to inspire and reiterate for further sampling.

### 4. Current Findings

The research has successfully created functional woven e-textile soft circuits (examples in Figure 2.).



**Figure 2. Left: woven LEDs in an e-textile. Right: Woven as one piece, soft switches that control two independent LEDs**

These are preliminary samples, but have offered a foundation to build and develop further that will help to strengthen into more sophisticated outcomes. The

ability to use woven methods for interactive e-textiles that are able to react has proved to be possible. Woven manipulations techniques have enabled the integration of some electronic components (both standard and e-textile tailored components) during the weaving process, whilst also allowing to imitate electronic circuit behaviours simultaneously (i.e. soft battery holders, soft switches, connectors and resistors).

### 5. Discussion

Challenging existing weaving methods have produced a collection of e-textile soft circuits. Analysis of the experimental e-textiles outputs are implemented back into the design process to improve on and translate to build designs for further transformable and modular e-textile configurations. These samples are used as drivers to direct the next sampling range, which are an ongoing process to simplify and manipulate woven techniques that are suitable for e-textiles. Each collection seeks to improve and challenge novel approaches and functions of woven e-textiles.

E-textiles have vast application in future products. As new technologies and interactive connected products are becoming popular amongst users, this will see more e-textiles being applied to these products.

### 6. Future Direction

The modular e-textiles will be applied to design research workshops with designers and laypersons to evaluate their design through an exploration of self-creating modular objects, and as probes to suggest appropriation for potential contexts of use. This would open dialogues of context for specific applications of woven e-textiles for future expansion of this research.

Future research will continue to work through an experimental design-focused process to develop more advanced woven e-textiles, on larger scales, with complex weave structures to progress them onto power and jacquard looms for potential commercial weaving.

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# **ISWC 2012**

## **Tutorials and Workshops**

ISWC 2012  
Adjunct Proceedings  
Newcastle Upon Tyne, UK on June 18-22.



# **Welcome message from the Tutorials and Workshop Co-Chairs**

The workshops at ISWC 2012 focus on hands-on experience as well as to introductory presentations on relevant topics to wearable computing. The aim of workshops is to bring together experts in complementary topics of the symposium with focus on case studies and actual implementations. There will be three workshops: 1) An Introduction to prototyping with the Arduino for the Software Engineer, 2) How to industrialize Wearable AR? - 1st Workshop on Wearable Systems for Industrial Augmented Reality Applications, and 3) Clothing in Motion: An Exploration of Wearable Technologies for Fashion, Wellness and Dance. We want to thank all contributors for your efforts and look forward to meeting you in ISWC 2012 workshops!

Sincerely,  
Juha Pärkkä & Christian Bürge



# An Introduction to prototyping with the Arduino for Computer Scientists

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## Abstract

*Developing electro-mechanical prototypes is a powerful skill set that allows researchers to uncover new ground by creating devices that are not commercially available. Today, powerful micro-controllers have become low cost and are very accessible to a broad audience. The goal of this workshop is to introduce the Arduino micro-controller to both beginners and those well versed with other micro-controller platforms. The Arduino micro-controller is a simple open source hardware platform with a low entry level, making hardware prototyping easily accessible to those without electronic engineering degrees.*

*Attendees will use a Sparkfun Inventors Kit to make their own powerful electronics circuits that are particularly well suited for building prototype devices. The Arduino Inventor kit comes with all the components to make your own hardware designs including features such as flashing LEDs, control of a DC motor, driving a servo, sounding a buzzer, detect light levels, measure bends with a flex sensor and more. All using a USB interface for both power and data communications so that no additional batteries are required.*

*The session will start with a short introduction to the Arduino features and capabilities, followed by an interactive workshop to set up the Arduino development environment on the attendees' own laptop. Following this you will work through projects from the Sparkfun Inventors kit with the option to begin a project of your own hardware design. Finally, a short presentation will describe Arduino add-ons available that can be employed to further expand the functionality of future prototypes.*

## 1. Outline

### Objectives

- Introduce the Arduino Micro-controller platform
- Set up the Arduino software development environment
- Complete Inventor Kit introduction projects

- Begin development on self directed project

### Significance

- Arduino's are accessible and have a low entry level
- Provide a powerful, generic and modular platform
- Platform independent programming and integration
- Provided in a variety of form-factors

### Target Audience

- No existing experience in micro-controller or embedded development required
- Basic computer programming knowledge is desirable
- Those familiar with other micro-controller platforms other than Arduino

### Agenda

- Introduction to the Arduino presentation (.25 hours)
- Set up Software Development environment (.5 hours)
- Working through hardware tutorials (3 hours)
  - Flashing a LED light
  - Reading from a Potentiometer to Laptop
  - Measuring Light Level using a photo cell
  - Driving a DC Motor with a transistor
- Time for self directed project designs (1 hour)
- Summary of Arduino Shields (.25 hours)

## 2. Biography

Dr Ross Smith is the Deputy Director of the Wearable Computer Laboratory and a Research Fellow at the University of South Australia with a passion for developing electro-mechanical prototypes to support new forms of human-computer interaction. His research strengths include deformable surfaces, spatial augmented reality, input device hardware development and user interface design. His vision is for a method of computer interaction that employs deformable devices that can be squashed, twisted and manipulated to create a rich set of gestures to support new form of human-computer interaction.

# **Clothing in Motion: An Exploration of Wearable Technologies for Fashion, Wellness and Dance**

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## **Abstract**

Since the late 20th century, fashion designers and engineers have experimented with incorporating various technologies into textiles in order to enhance their functionality and aesthetic qualities. This workshop begins with a presentation of four projects, all conducted with Arizona State University, to illustrate the wide range of possibilities of wearable technologies in fashion, personal wellness, and dance performance. To begin, the Sensory Chameleon Bodysuit (2004) showed how wearable technologies may influence human health and safety. Innovations in the field of textiles also offer new possibilities in dance performance. The concert Motion-e (2004-2005) included wearable technologies that influenced light and sound. Paper Interiors (2002) utilized special textiles that interacted directly with external technologies and multimedia to create a unique 3D viewing experience. Last but not least, the Telematic Dress (2008-2011) challenged the traditional viewpoint that a live performance required dancers to be in the same space. After the presentation, participants will divide into groups and work hands-on with textiles and electronics to create kinetic dresses. Each group will receive a hand-out with instructions and suggestions. Finally, the groups will present their product and explain how their dress functions and how they chose to incorporate various technological components. The workshop will conclude with a discussion about key design issues and concepts.

## **1. Outline**

**Objectives:** To explore ideas regarding how technologies embedded in textiles can influence the textile wearer and the environment.

**Significance:** The future of design and textiles will be a collaborative process, requiring people from different fields to work together. Participants' discussions will provide invaluable feedback regarding future research in this field, which addresses how designers can assist with the process of creating smart clothes and bringing them to the general public in an appealing manner.

**Target Audience:** Fashion designers, engineers, chemists, choreographers, artists, etc.

### **Agenda:**

- A. PowerPoint presentation, 20 minutes
- B. Workgroups to create kinetic dresses, 2 hours
- C. Break, 10 minutes
- D. Resume workgroups, 1.25 hours
- E. Group presentations, 30 minutes
- F. Discussion, 45 minutes

## **2. Biography**

Galina Mihaleva is a Doctoral Candidate in Textile Arts at the National Academy of Fine Arts, Sofia, Bulgaria, where she also received her Master's degree in Textile Arts and Clothing Accessories. She is Adjunct Faculty in the Fashion Design Program at Phoenix College, Phoenix, Arizona as well as Costume Shop Coordinator in the School of Dance at Arizona State University, Tempe, Arizona. Besides that, Galina runs her own couture boutique in Scottsdale, Arizona.



# How to industrialize Wearable Augmented Reality?

## 1<sup>st</sup> Workshop on Wearable Systems for Industrial AR Applications

Christian Bürgy, Juha Pärkkä  
Bruce Thomas, Thuong Hoang, Michael Lawo, Holger Kenn

### Abstract

Augmented Reality (AR) is a successful application area of Wearable Computing, especially for professional, industrial settings, in which mobility is an important factor. With the proliferation of mobile technology in the workplace, wearable computing research can offer a valuable contribution to the usability of mobile solutions, such as the use of context information to inform devices and services of the current task and user situation, relieve professionals of tedious and repetitive information entry tasks and increase worker safety in complex and hazardous environments. Wearable AR systems in general are widely utilized in various domains, including architecture, military, tourism, navigation, and entertainment. Such diverse usages impose several challenges on researchers from both areas of Augmented Reality and Wearable Computing, such as interaction, activity and context recognition, wearability, design, and modeling. We invite researchers from relevant disciplines to a one-day workshop held in conjunction with ISWC 2012 to present novel works and discuss the application of state-of-the-art Wearable Computing research to Augmented Reality systems. The workshop also provides an opportunity for directed discussion sessions to identify current issues, research topics, and solution approaches, which lead to the proposal of future research directions.

### 1. Outline

**Objectives:** The objective of this workshop is to bring together researchers from academia, professional hardware and software developers and current and future users of wearable systems. We want to stimulate the application of Augmented Reality on wearable systems in professional environments.

**Significance:** Wearable Computing systems and Augmented Reality applications will more and more become part of daily experience with mobile computing systems. To design and develop such systems, hardware and software experts as well as designers of user interaction and work processes need to collaborate extensively. This workshop will start a discussion, which could lead into such a direction.

**Target Audience:** users, experts and developers of Wearable Computer systems and/or Augmented Reality applications from academia and from industry

### Agenda:

After a series of presentations, we will move into a moderated discussion to generate a list of necessary steps, which might help to answer the question of “How to industrialize Wearable AR?” – The goal is to establish a continuing exchange on the topics and review the results in a future workshop.

### 2. Biography

**Dr. Christian Bürgy** is managing partner of teXXmo Mobile Solution GmbH & Co. KG, a company, which provides mobile and wearable computing solutions to industrial customers. In this position, he led and leads several research projects on Wearable Computer systems and Augmented Reality with academic and industrial partners. Christian holds a diploma degree in Civil Engineering from Technical University in Darmstadt, Germany and received his Ph.D. in Computer-Aided Engineering and Management from Carnegie Mellon University in Pittsburgh, PA, USA. In his Ph.D. research, he had a stipend from Bosch Corporation to study interaction modalities with wearable computing systems in industrial environments.

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**Dr. Juha Pärkkä** is a Senior Scientist at VTT Technical Research Centre of Finland. He received the M.Sc. (Tech) and D.Sc. (Tech) degrees in information technology - digital signal processing - from Tampere University of Technology, Tampere, Finland, in 1997 and 2011, respectively. His research interests include biomedical signal processing, ubiquitous computing and personal health systems.

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**Prof. Bruce H. Thomas** is the Deputy Director of the Advanced Computing Research Centre and Director of the Wearable Computer Lab. He is nationally and internationally recognised for his contributions to the scientific community and to industry in the areas Wearable Computers, Tabletop Interactions, Augmented Reality, and User Interaction. Bruce holds a Master's degree in Computer Science of University of Virginia, Charlottesville, VA, USA and received his Ph.D. in Computer Science from Flinders University of South Australia.

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**Thuong Ngoc Hoang** is a Ph.D. candidate in Computer and Information Science at University of South Australia. Her holds a Bachelor of Information Technology in Advanced Computer and Information Science of the same university and received a Diploma in Information Technology by South Australia Institute of Business and Technology (SAIBT). His research activities involve participation in the Tinmith project, wearable computing in general and outdoor augmented reality with focus on interaction techniques for outdoor augmented reality.

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**Prof. Dr. Michael Lawo** is since 2004 at TZI of the Universität Bremen, and since 2009 Managing Director of neusta mobile solutions GmbH. He is professor for applied computer science at Universität Bremen, member of the steering board of Logdynamics and involved in numerous projects of logistics, wearable computing and artificial intelligence. Michael was consultant before joining the nuclear research centre in Karlsruhe from 1987 to 1991 as head of the industrial robotics department. He is a 1975 graduate of structural engineering of Ruhr University Bochum, received his Ph.D. from University in Essen in 1981 and became professor in structural optimisation there in 1992. In 2000 he was appointed as professor of honour of the Harbin/China College of Administration & Management.

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**Dr. Holger Kenn** holds a diploma degree in computer science from the Universität des Saarlandes in Saarbrücken, Germany and a Ph.D. from Vrije Universiteit Brussel, Belgium. In 2001, he became Lecturer of Electrical Engineering and Computer Science at the newly founded Jacobs University in Bremen, Germany where his research focused on autonomous mobile multi-robot systems for urban search and rescue. From 2004 to 2007 he worked as senior scientist at the TZI at Universität Bremen, Germany on research topics in wearable computing. Since 2007, he works for Microsoft Research at the Advanced Technology Labs Europe in Aachen, Germany on embedded systems and system-level software.

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# **ISWC 2012**

## **1<sup>st</sup> Workshop on Wearable Systems for Industrial AR Applications**

ISWC 2012  
Adjunct Proceedings  
Newcastle Upon Tyne, UK on June 18-22.



# Mobile Order Picking using Pick Charts: Industrial Usage and Future Work

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## Abstract

*Order picking is most often performed with a paper pick-list, which lists the parts required to fulfill an order. To reduce errors and increase picking speed, technologies such as “pick-by-light” have been developed. While successful, such systems are expensive to deploy and update. In previous work, we demonstrated the advantages of a less costly mobile picking solution using graphical representations (displayed on a head-mounted display (HMD) or a tablet-PC) of what to pick. Here I present our current work in progress, suggestions for future work and talk about potential usage in industry.*

## 1. Previous Works

In previous work [1] a pick list presented graphically on a wearable computer with a HMD enabled faster picking than the same graphical representation on a paper pick list, a pick-by-voice system and a standard text-based pick list. For convenience, I refer to the graphical representation of where to pick parts from a shelving unit as the **pick chart**. Subjectively, the HMD system was preferred overall to the other methods, and it resulted in fewer errors and less overall task load than the text pick list. In our latest study, also presented at the ISWC 2012, we evaluated the use of the pick chart based solution on a HMD (pick-by-HMD) and a tablet-PC (pick-by-tablet), comparing it against pick-by-light and a paper pick list in an industrial environment with experienced workers. In this study, the pick chart based solutions were able to reach a performance far better than paper pick lists and close to pick-by-light.<sup>1</sup>

<sup>1</sup>Please refer to our ISWC main conference poster and full workshop paper for further details.

## 2. Industrial Usage

Based on the results and the observations of the studies, I am convinced that our proposed pick chart based solution could be used beneficially at many picking lines, where currently paper pick lists, pick-by-voice or hand held devices are used.

In dense picking environments, pick-by-tablet will directly reach a significant improvement in performance compared to paper pick lists or pick-by-voice. While pick-by-HMD would also reach a better accuracy and faster picking, I recommend not to introduce it yet for industrial usage as the hardware solution and the user acceptance will need further investigations.

Only a small improvement can be expected in less dense picking environments when switching from paper pick lists or pick by voice to a pick chart based solution (less complexity will reduce errors and walking will require the most time anyway). As the pick chart based solutions can handle much more complex picking tasks with very low error rates, picking density can be increased by changing from single order picking to batch picking (or increasing the number of orders performed at once) when feasible. As a result, pick-by-tablet (and pick-by-HMD) will achieve a higher speed while maintaining or even improving the error rate.

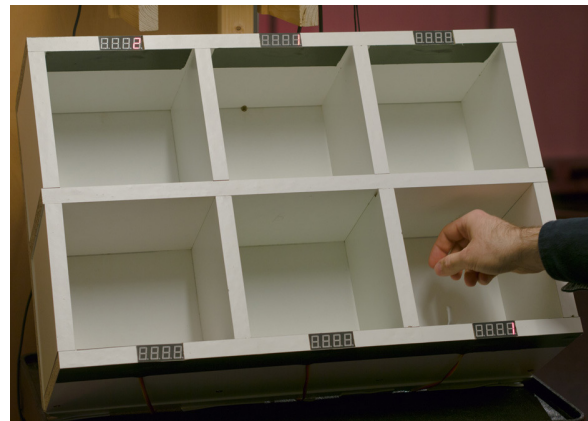
Looking on the required investment costs, the pick chart based approach will require little higher investments compared to paper pick lists, while being much less expensive and also more flexible than pick-by-light. Picking lines can be of any length without increasing the investment costs for pick-by-tablet or pick-by-HMD (assuming that the shelves are already available). For pick-by-light in contrast, the investment costs will increase with every pick location. Also if the picking line needs to be extended with new pick locations (for example by making pick locations smaller) for the pick chart based solution, only a configuration of the setup file for the shelves is needed. For pick-by-light in contrast, old

units would need to be rearranged and new pick-by-light must be bought and installed. Also the operating costs of pick-by-tablet will be very low, comparable to pick-by-voice and – if pick lists are not needed – probably cheaper than paper pick lists due to the printing costs.

### 3. Current and Future Work

To increase the performance even more, I suggest to use a place detection for the pick cart as evaluated in our latest study. Such a place detection reduces the possibility of placing an item into the wrong order bin. Additionally, it allows an automatic transition to the next pick step improving usability and speed without increasing the investment costs a lot. Although not evaluated yet, it stands to reason that put-to-light displays on the pick cart will help the worker to find the correct order bins even more quickly and reliable when many orders are performed and sorted at once. With pick-by-tablet such displays could be directly controlled from the tablet PC by a serial interface, resulting in only slightly increased investment costs. We are currently working on a prototypical pick chart based pick-by-tablet solution with put-to-light (see Figure 1). The pick cart of this prototype consists of six order boxes in two rows. Above (for the upper row) respectively under (for the lower row) each order box, a 7 segment 4 digit display with serial interface is attached and connected to the tablet PC. This arrangement is chosen to avoid accidentally placing an item into the wrong row. To indicate a required place, the display is continuously changing the brightness between a low and high brightness back and forth while displaying the required number of items to be placed into the order bin. After the corresponding place is detected, the brightness stops pulsing and the number of items that have been required is shown at a constant and reduced brightness.

While I still see potentials for the use of pick-by-HMD, I would not recommend to introduce it by now for industrial usage, as the hardware solution and user acceptance in my opinion will need further investigations. The used SV-6 HMD from MicroOptical has the advantages of being lightweight, well readable in bright environment, only marginally occludes the human field of vision while being used, and it also allows to adjust the focus distance of the virtual display. Unfortunately, this HMD is not sold anymore by MicroOptical (another drawback was that the cables tended to get a defective after a while). For this reason, other HMD alternatives like the Golden-i have to be considered. As advantage, this HMD already includes a computing unit while being still comfortable to wear. A disadvantage is however,



**Figure 1. Pick cart with Pick-by-tablet and Put-to-light**

that the HMD occludes much more of the field of vision (even if worn out of normal line of sight).

### 4. Conclusion

A previous study showed a better performance for the mobile pick chart based solution in a dense picking environment compared to paper pick lists and pick-by-voice. In our latest study, in an industrial environment with experienced workers, we saw that the performance of pick-by-HMD and pick-by-tablet is close to the performance of pick-by-light and that the user acceptance for pick-by-tablet was mostly positive. The hardware solution and user acceptance for pick-by-HMD will require further investigations.

I feel certain that pick-by-tablet shows a high potential. It can be used at many picking lines where a pick-by-light solution would increase the performance, but is not economically to deploy because of the high investment costs and low flexibility. If an even higher performance is required I suggest to use a place detection and a picking cart with a put-to-light setup in combination with the pick chart based tablet solution.

### References

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# Evaluation of a Mobile Order Picking Solution in an Industrial Environment

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## Abstract

*Order picking is most often performed with a paper pick-list, which lists the parts required to fulfill an order. To reduce errors and increase picking speed, technologies such as “pick-by-light” have been developed. While successful, such systems are expensive to deploy and update. In previous work, we demonstrated the advantages of a less costly head-mounted display (HMD) based picking chart over a traditional text-based pick list, a paper-based graphical pick chart, and a mobile pick-by-voice system. We now present the results of a study conducted in a running assembly plant of a large automobile manufacturer, comparing a picking chart – displayed on a wearable computer with a head mounted display (HMD) or a tablet PC – against a text-based pick list and a pick-by-light system.*

## 1. Introduction

Order picking is a commercially important activity in industry [1], representing up to 65% [4] of the total operational costs of a warehouse. Highly automated picking methods exist in constrained domains, but 80% of picking is still performed manually in Western Europe [6], partially due to technical obstacles and cost. Often, a text-based paper picking list is used for manual order picking. Such a list specifies – in a given sequence – the needed items and the required number of these items. Many methods have been developed to assist the manual order picker, including pick-by-voice and mobile RF-based solutions [7]. These systems are best suited in warehouses where a worker must travel between the picks. If there are often many items to be picked within just one shelving unit, pick-by-light is more appropriate. Pick-by-light systems are perhaps the most advanced manual order picking aides in dense picking environments with respect to speed and low error-rates; lights

mounted under each pick-location indicate which parts to pick, and buttons next to the lights are used to confirm a pick or put [2]. Some systems also offer proximity sensors or laser scanners to confirm the picks and puts of a worker [9]. However, these systems require a high initial investment, making them often uneconomical. Here, we investigate less costly alternatives based on mobile computing.

Reif et al. [8] created an HMD based augmented reality system to guide the picker to each part using arrows and attention tunnels. This system however, seems to be more appropriate in picking environments, where a worker needs to travel between the picks. Also industry started to offer an HMD based augmented reality system for order picking [5].

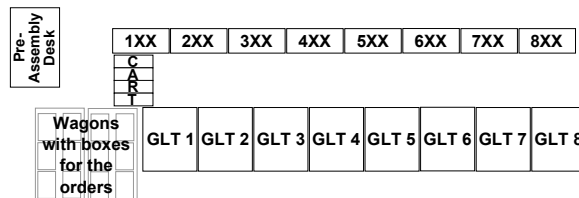
In previous work [12] (using a dense picking environment), a pick list presented graphically on a wearable computer with a HMD enabled faster picking than the same graphical representation on a paper pick list, a pick-by-voice system, and a standard text-based pick list. For convenience, we refer to the graphical representation of where to pick parts from a shelving unit as the **pick chart**. Subjectively, the HMD system was preferred overall to the other methods, and it resulted in fewer errors and less overall task load than the text pick list. Based on suggestions by subjects and interaction principles in the literature, we developed and evaluated different extensions for this pick chart [3]. The goal was to further decrease the error rate by improving the graphical representation of the pick charts and by introducing context feedback. While the context feedback – in form of a pick detection with a graphical visualization – showed about one third fewer errors (without being significant), one of the extensions – the use of colors that match the rows of the shelves with the rows of the pick chart – showed a reduction of the error rate by more than 50%. Similar to the graphical pick chart, industry developed a new solution also using graphical representations of the shelves [11].



Here, we present the results of a user study performed in the assembly plant of a large automobile manufacturer comparing the picking chart – on a wearable computer with a HMD or a tablet PC – against a text-based pick list and the manufacturer’s established and highly efficient pick-by-light system. We focus on user acceptance and workload of experienced workers but also examine error-rate and picking speed with these systems. We wish to estimate the practical value of a mobile pick-chart based solution for industry as compared to pick-by-light and pick-by-paper.

## 2. Task and Picking Environment

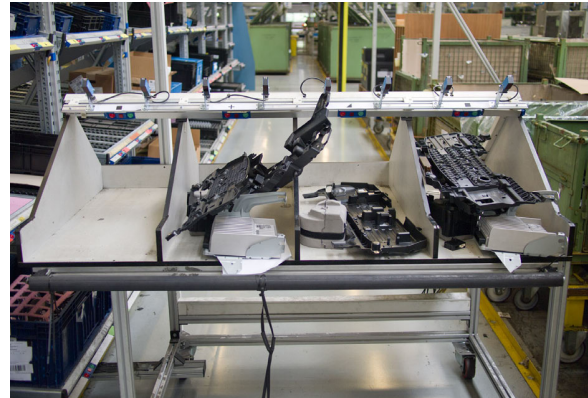
Figure 1 and 2 illustrate the picking environment. The rectangles labeled *1XX* to *8XX* indicate the shelving units; *GLT 1* to *GLT 8* are large load carriers (GLT) for larger items. The pick cart runs on rails between the two rows and has four order bins, one for each car being assembled. Each shelving unit has three rows for picking. Typically the upper and middle row have three pick (and three pick-by-light) locations, while the lower row has typically two pick locations. As parts change over time and the width of the boxes in the shelves vary, some unused pick locations may be partly consumed by a bigger box from a bordering pick location.



**Figure 1. The picking environment**

We used the same pick- & put detection sensors normally used by the Safelog pick-by-light system [9]. Laser range-finders (LRF) mounted in front of the normal shelving units and large load carriers detect picks. Two infrared sensors over each order bin detect puts on the pick-cart. Every pick-location and order bin has a pick-by light unit with an integrated button which could be used as an alternative to the automated pick- & put-detection (in case a pick or put was not detected automatically).

A worker completes four orders at once. Print-outs of the next four orders are placed into the order bins in the pick-cart, independent of the picking method used. When the worker starts a picking task, he confirms that the next orders correspond to the orders noted on the prints in the picking-cart. Next, he pushes the pick-cart



**Figure 2. Pick-cart (center), normal shelves (left), and large load carriers (right)**

along the shelves, picking all items necessary for the four orders using one of the picking methods described in Section 3. When finished, he returns the pick-cart, retrieves an empty box for each order from a nearby wagon (Figure 3b) and fills that box with the corresponding items. Some items are assembled while filling the orders (Figure 3a). The picker has the option to verify the picked items with the order print-outs. After placing the filled box on the wagon, the participant is ready to continue with the next task.

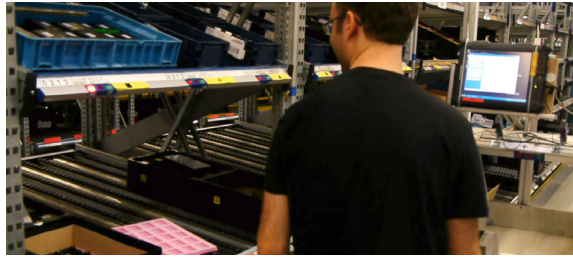


**Figure 3. Order boxes**

## 3. Picking Methods

### 3.1 Pick-by-light

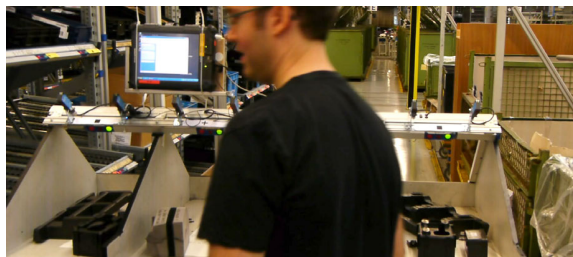
Pick-by-light is the normally used method at the pick line. Figure 4 describes how picking with pick-by-light is generally performed. With the exception of the items at pick location 113, all items are needed once per order. If required, the items at pick location 113 are needed



(a) A red light indicates the next pick location



(b) After pick detection, the light turns green and red lights on the pick-cart indicates where to put the items (and how many items are needed in total)



(c) After every put the corresponding light on the pick-cart turns green (the next pick location is shown after the last put of the previous item)

**Figure 4. Pick-by-light**

two times per order. This detail is known by all workers on this line, and thus the total amount of items needed can be inferred by the amount of lights displayed on the pick-cart.

### 3.2 Pick-by-HMD

For pick-by-HMD, workers wear a vest with a teXXmo TX-1000 Wearable PC using a 1.6GHz Intel Atom Z530 and 1GB of RAM (Figure 5a). Pick charts are displayed on a MicroOptical SV-6 (an opaque, monocular HMD) mounted on safety glasses with the lenses removed. Independent of the eye dominance, the HMD was always worn over the worker's right eye.<sup>1</sup> To

<sup>1</sup>In a previous study, we observed that wearing the HMD over the left eye reduced the wearer's attention with respect to the pick chart

compensate the weight of the HMD, we added a counterweight to the left side of the safety glasses. A Vuzix rugged mouse with two large buttons allows navigation and is carried vertically near the right hip (Figure 5b) or is attached to the pick cart and connected wirelessly. Section 4 describes the pick chart variations tested.



(a) Back: wearable computer, (b) Front: rugged mouse and battery status LED antennas

**Figure 5. Pick-by-HMD**

### 3.3 Pick-by-tablet

For testing pick-by-tablet, a tablet PC and the Vuzix mouse were attached to the pick-cart for testing. We started with a teXXmo Kaleo GX tablet PC but soon switched to an xplore iX104 tablet PC due to instability in the graphics during animations. For pick-by-tablet we used the same pick chart variations as with pick-by-HMD (see section 4).



**Figure 6. Pick-by-tablet**

and that both left and right eye dominant participants performed well when the HMD was worn over the right eye.

### 3.4 Pick-by-paper

Two slightly different pick-by-paper variations (Figure 7) were printed on DIN-A4 sized paper. The top row shows the orders of the current task (in Figure 7, order 74, 75, 76 and 77). The leftmost column shows the pick-locations of the items needed for the orders. In Variation 1, in addition to the pick-locations, the total number of needed items is shown after the prefix “x” (in cases where in total the amount is more than just one item). The four following cells show the number of items needed for the corresponding order.

	074	075	076	077
113 x 2			2	
123			1	
133 x 2		1		1
1			1	
213 x 3		1	1	1
223	1			
2			1	
331	1			
3	1			
423 x 2	1			1
421 x 2		1		1
4	1			
511 x 2		1		1
613		1		
612 x 2		1		1
622		1		
6	1			
8 x 2		1		1

(a) Variation 1

	074	075	076	077
113			2	
123			1	
133		1		1
1			1	
213		1	1	1
223	1			
2			1	
331	1			
3	1			
423	1			1
421		1		1
4	1			
511		1		1
613		1		
612		1		1
622		1		
6	1			
8		1		1

(b) Variation 2

Figure 7. Pick-by-paper

## 4. User Interface and Variations

To start a new task, the worker double-clicks the forward-button on the mouse (the other mouse button was defined as the backward-button). The first screen of the task appears showing the current order numbers (see Figure 8a). The user verifies the order numbers with the prints in the four order bins. With another forward-button press, the picking procedure starts. After all parts of a task are finished, a final screen informs the worker that he is ready for the next task (see figure 8b).

### 4.1 Pick-step and Pick-chart visualization

A pick task is divided into pick-steps. A pick-step consists of either: *one pick location and all corresponding receiving bins* or *one receiving bin and all corresponding pick locations of the current shelf*. If optimization is not used (see Section 4.4), the first variant is always used (corresponding to the normal ordering of

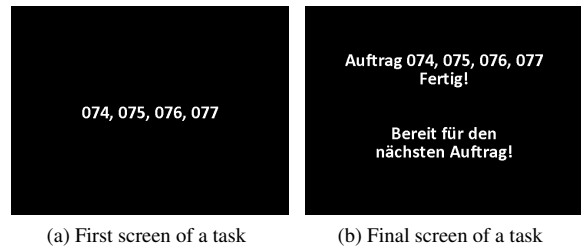
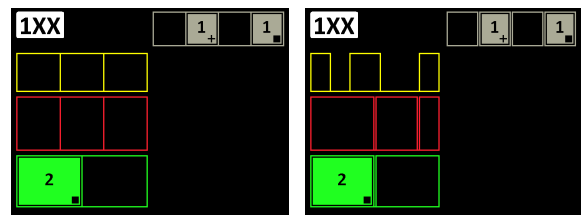


Figure 8. First and final screen of a task

the pick-by-light system). Every pick-step displays on a separate screen. We tried two slightly different pick-chart visualizations. The *abstract visualization* (Figure 9a), displays every existing pick-location independently of the currently used boxes and box-widths. For the *concrete visualization* (Figure 9b), location and width of the boxes were considered, and unused pick locations were not shown.



(a) Abstract shelf visualization

(b) Concrete shelf visualization

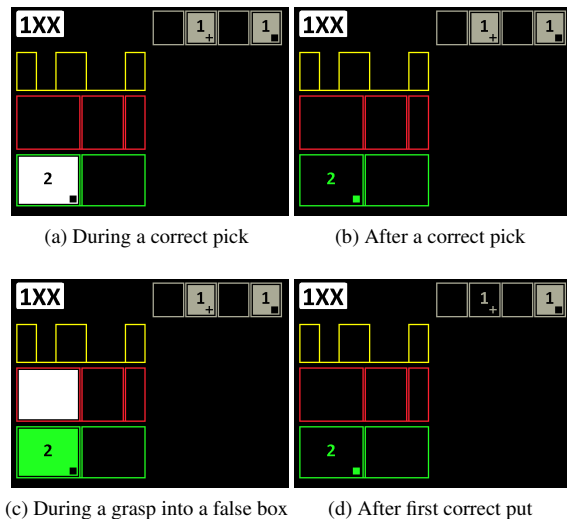
Figure 9. Shelf visualization

In the pick chart in Figure 9, the shelving unit identifier (*1XX*) is shown at the top-left of the screen. If this identifier is black with a white background, then the previous pick-step was from a different shelving unit. The picking chart shown indicates that the worker should pick two items from the bottom-left box of the shelf and put them into the second and fourth order bin of the pick cart (order bins are shown in gray on the top-right of the screen). The colors and symbols on the pick chart correspond to labels shown under each box on the physical shelves or over the order bins on the pick cart.

### 4.2 Picking procedure, pick- & put-visualization and shelf changes

To complete a task, a worker must complete all pick-steps as they are presented to him sequentially. If pick-detection is used, a part bin is highlighted in the pick-chart during a correct pick (Figure 10a). Afterwards, the part bin reverses background and foreground color to in-

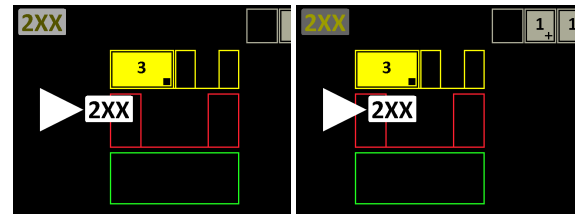
indicate that the part was correctly picked (Figure 10b). A reach into a wrong part bin highlights the incorrect part bin in the pick-chart (Figure 10c). Afterwards the part bin gets normally visualized like before. Put-detection was used during the whole study. During a put, the corresponding order bin in the pick-chart is highlighted and reversed afterwards (Figure 10d).



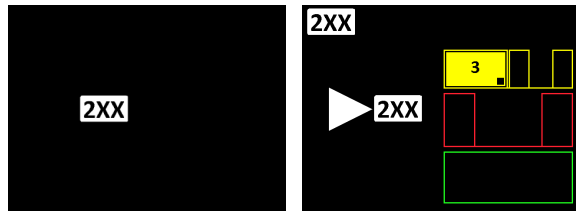
**Figure 10. Pick detection**

A pick-step is finished when all picks (when pick detection was used) and puts of the current pick-step are detected. After a pick-step finishes, depending on the setting used, the system either switches to the next pick-step automatically or the worker has to press the forward-button. If the next pick-step is within the same shelf as the previous pick-step the next pick-step will be shown instantly. If the next pick-step is within another shelf, depending on the setting, the system will

- show an animation with an arrow and the shelf identifier in front, moving the pick-chart from the left side of the screen to the normal position (Figure 11a).
- show an additional screen asking for user confirmation (Figure 11b).
- show an arrow and the shelf identifier on the left side and the pick-chart on the right side. For this variation, after a confirmation or a detected pick from the correct shelf, the arrow and shelf identifier disappear and an animation moves the pick chart to the normal position (Figure 11c).



(a) Shelf change with animation



(b) Shelf change with extra screen (c) Shelf change with translated pick-chart

**Figure 11. Shelf change**

If a worker wants to check a previous pick-step, he can page back through the pick-steps with the backward-button (a green dot indicates previously finished pick-steps). Afterwards the worker pages forward through the pick-steps with the forward button till he reaches again the last shown and unfinished pick-step, indicated with a gray dot. The system does not allow paging forward through unfinished pick-steps.

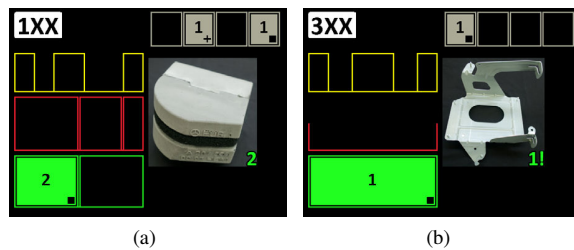
### 4.3 Part-images

Optionally, part images could be shown on the right side of the screen (Figure 12a). To ensure that the worker attends the number of items to pick (this problem was observed in our previous study [3]), the number of items were rendered at the bottom-right of the part image in the color of the corresponding row. Additionally, the system showed one or more exclamation points behind the number of items for the parts where similar parts existed, to avoid an accidental substitution of these parts (Figure 12b).

### 4.4 Optimization and audio feedback

If optimization is switched on, the system compares the amount of movement required for a shelving unit using a policy of either displaying *one pick location and all corresponding receiving bins* or *one receiving bin and all corresponding pick locations*. The worker is prompted with the shortest combination of movements. In the pick-task shown on the paper pick list (Figure 7),





**Figure 12. Visualizations with object images**

for example, two optimizations would be possible: one within the shelving unit *1XX* (showing pick-location *1/3* and *1/23* at once for order *076*), and one within shelving unit *6XX*.

Optionally, we could turn on audio feedback for the pick- and put-detection. Whenever a correct pick or put was detected, a short audio sample was played as feedback.

## 5. Method

Our study occurred during regular plant operations. Due to time constraints and policies regarding the capture of employee performance, video recordings, questionnaires and explicit records of time measures were not permitted. Normal research methods [12, 3] had to be modified strongly. Therefore, we used simplified qualitative methods like open questions to discover previously unknown facts as well as elements of ethnographic study (e.g. observing the behavior of the subject while working with the picking solution).

We emphasize the significance that the picking facility provides parts directly to a running assembly line process, where interruptions within the supply chain had to be avoided. Orders need to be picked and pre-assembled continuously to satisfy the demands of the assembly line. For this reason, no special training sessions are possible, and the workers need to fulfill the demand of the picking-line with the wearable or the tablet solution from the beginning. Experimenters support the subjects at the beginning of each condition and also explained the system in more detail while the first tasks are performed. On demand, experimenters also help with secondary tasks to reduce the workload and time pressure for the worker.

Worker participation in the study is based on agreeing to try the wearable or tablet solution. To encourage feedback and insure cooperation, we present different

variations of the interfaces to the worker and always let him use the combination which he prefers. However, we encourage workers to try at least a few tasks (a task consisted of an average of 15 pick-steps in the unoptimized conditions) with each variation to allow familiarization.

While the subject was performing pre-assembly tasks, secondary activities or during his personal allowance time, the subject was asked to provide feedback regarding the general method and the current interface variation. Based on the experimenters' observations and memory of the subjects' feedback, experimenters wrote notes for later evaluation. After the worker tried a first method, the experimenters asked him to try the other pick-chart based method or one of the pick-by-paper variations.

The study had one permanent experimenter<sup>2</sup> who was always (with exception of a few breaks) at the picking line if one of three methods (pick-by-HMD, pick-by-tablet or pick-by-paper) was used. A second experimenter<sup>3</sup> supported the first in observing, asking questions, taking notes, discussing observations, etc. When necessary a third experimenter<sup>4</sup> was available in the absence of one of the other experimenters.

During the study, seven experienced workers used pick-by-HMD, and eight experienced workers used pick-by-tablet. Five workers tried both methods. Pick-by-paper was used by four workers (all of whom used at least one of the other methods).

## 6. Accuracy

We intended to compare two different types of errors: mistakes noticed by the experimenters or the worker himself before the order left the picking line and mistakes detected by quality management after the orders left the picking line. Fortunately, no errors were observed by quality management; thus, we focus on the former class of mistakes.

During the shorter observation periods dedicated to the pick-by-light method, no mistakes were observed on the picking line. However, 2 mistakes were observed during the 276 tasks (corresponding to 4016 pick-steps, 4459 picks<sup>5</sup>, and 5839 puts) performed using pick-by-HMD. No mistakes were observed during the 113 tasks (1847 pick-steps, 1855 picks, and 2655 puts) performed with pick-by-tablet. At least one error was observed in 10 of the 16 (non-training) tasks that used paper pick

<sup>2</sup>The first author of this paper

<sup>3</sup>The co-author from Daimler AG, Plant Mannheim

<sup>4</sup>A colleague of the first author

<sup>5</sup>Without optimization, the number of picks equals the number of pick-steps.

lists. Of the four workers who tried pick-by-paper, all committed errors on at least 50% of their tasks. Omitted parts were the main errors with paper pick lists, as workers had difficulty keeping track of their progress. Thus, while mistakes may have decreased as workers gained more experience with pick-by-paper, we feel quite sure that pick-by-paper would have shown significantly more errors than all the other methods in a controlled study.

## 7. Speed

Due to requirements for protection of data at the plant, we can only report our subjective observations regarding picking times. Initial tasks using pick-by-HMD definitely needed more time than with the normal pick-by-light system. When first introduced to the HMD, every participant needed some time to adjust its focus and position. Most workers tried to optimize these HMD settings several times during their first tasks. Focusing and reading from the HMD also seemed to be slower at the beginning (many subjects looked strained reading the HMD). A few subjects also required some time to accustom themselves to the pick-chart concept. One subject needed a few seconds to interpret the pick chart correctly for every pick-step at the beginning. While after a few tasks the process improved, the worker definitely was not able to achieve the same speed as with pick-by-light (though he did not try using part images with pick-by-HMD). To compensate for the increased picking times – as already noted before – experimenters helped the subjects with some secondary tasks.

One subject used pick-by-HMD over a longer time over whole shifts. Given this practice, the subject was able to perform the work easily without the need of help. Another subject who used the system for over 4 hours/day for two days was able to fulfill his work without the need of support. However, he seemed to have more time pressure than when using his normal pick-by-light system. Given our observations, we suspect that pick-by-HMD is slower for novices than pick-by-light but that the difference will narrow with practice, with pick-by-light still being faster in the limit. A more controlled study is needed to determine the relative speeds of both systems when used by experts.

With pick-by-tablet, most workers were quite fast from the beginning and further improved their speed after some practice. As with pick-by-HMD, a few subjects needed some time to adapt to the pick-chart. The subject who was slower in interpreting the pick-chart with pick-by-HMD also needed notably more time for interpreting the pick-chart using pick-by-tablet. However, when we used the extension with part-images he became notably

faster, achieving a speed comparable to the other workers.

In comparison to the other methods, we saw that at the beginning pick-by-tablet was slower than with the worker's normal pick-by-light system, but faster than beginning with pick-by-HMD. However, with expert usage, we suspect that pick-by-HMD could be faster than pick-by-tablet as the HMD allows the worker to glance at the pick chart at any time as opposed to repositioning his head to see the display on the pick-cart.

Pick-by-paper seems to be a little slower than the other methods. When the worker got confused – for example in remembering which line he completed his last pick (which happened quite often) – picking times increased even higher. However, we observed a very high error rate with pick-by-paper, which is a much more important component than speed for most pick tasks.

## 8. User Acceptance and User Feedback

In the following sections, we collect user feedback and our observations on user acceptance for the different methods.

In general, workers like the current pick-by-light system, with the exception that the automatic pick detection is partially disliked as sometimes picks or puts are not detected. More rarely, picks or puts are detected when there was no pick or put (for example, when the worker's clothing brushes past a sensor).

User feedback regarding the HMD and tablet interface variations was comparable across the devices. The first subjects (all using the HMD) had a preference for the concrete visualization over the abstract visualization and highly preferred the automatic transition to the next pick step over pressing the forward-button on the mouse. To reduce the amount of parameters, we decided to continue with the concrete visualization and the automatic transitioning for the rest of the study.

After some practice, all participants preferred the animation showing the change in shelving unit. For a few subjects, we believe that the variation with the additional screen requiring an explicit confirmation for the shelving unit change, was helpful to become accustomed to the new picking method.

Part images were preferred from most subjects, but some participants preferred to work without the part images as the images distracted them slightly. Two subjects said that they mainly used the images for orientation, as they already knew all pick locations for the items.

At the beginning of the study we used the picking-detection system as we wanted to minimize the risk for mistakes. As we observed that all subjects (after a little

practice) picked very reliably from the correct part bins, we decided in the last 1.5 weeks of the study to allow subjects to try pick-chart based methods without pick-detection. Remarkably, while pick detection was turned off, no mistakes were made, and all subjects preferred to work with the pick-detection turned off (subjects felt that their work flow was interrupted when pick detection did not detect a pick instantly).

All subjects except one preferred to have audio feedback for every detected put (and pick, if picking detection was used). Optimization was tested by three participants. Two preferred to work without optimization as they felt that having a consistent work flow was easier. In contrast, the remaining subject liked the optimization as it saved work. Given the variations observed among workers, we suggest that pick-chart based systems include a set of user preferences to allow personalization of the interface.

## 8.1 Pick-by-HMD

At the beginning, most workers were quite skeptical regarding the pick-by-HMD approach. Many workers tried to avoid the picking line during our study, and four of the workers who needed to work at the picking line refused to try the pick-by-HMD solution. Some of the workers even tried to convince other workers not to try the pick-by-HMD solution as some of them were generally afraid of innovations which may bring drawbacks for their future (through worse working conditions, higher workloads, etc). These influences might have affected the subjective awareness of the workers who agreed to try the pick-by-HMD (and also pick-by-tablet) approaches.

From our estimation, before starting to use pick-by-HMD, only two subjects had a neutral attitude, four subjects had a more negative attitude, and one subject had a very negative attitude towards the use of pick-by-HMD.

When starting, all participants stated that pick-by-HMD causes some eye strain. Five subjects complained of problems like: difficulties to see the HMD-image, eye pain or concentration problems. Three subjects felt physically restricted wearing the equipment, and one subject mentioned that he started to sweat wearing the vest. One subject also said that he is slower with pick-by-HMD than with pick-by-light, causing him time pressure. For these reasons most subjects stopped using the pick-by-HMD approach before they had a chance to grow accustomed to the HMD.

One of the subjects with a neutral attitude (wearing varifocal glasses, but switching to his old normal glasses after some time) used pick-by-HMD for a longer time

(about 4 hours/day for two days). He reported some adaption to the HMD but stated there were still problems reading the HMD when looking into bright or inhomogeneous backgrounds. He also said he would prefer a bigger screen on the HMD. Besides the eye-strain, he liked the system and could imagine working with an improved pick-by-HMD solution.

Another subject (wearing glasses) with a neutral attitude at the beginning used the pick-by HMD system also for two days (4 hours/day). The subject felt restricted in his movements and clearly preferred pick-by-light over pick-by-HMD. For pick-by-light this subject reported a very low eye-strain and a low overall workload. For pick-by-HMD in comparison, he reported a high eye-strain and overall workload.

The only subject (not wearing glasses) who used pick-by-HMD over a longer time (over three weeks and most working days for at least four hours) changed from a more negative attitude at the beginning towards a more positive attitude regarding pick-by-HMD. The first three days the subject used pick-by-HMD for short periods, reporting eye-strain. As he was also our first subject, other workers watched and commented on the HMD approach. As a result the subject claimed that *All are watching, and I am looking like a Martian*. From the fourth day on the eye strain got much better, and the subject used pick-by-HMD for about four hours. After 1.5 weeks, eye-strain was finally gone, and the subject could work over whole shifts (8 hours) using pick-by-HMD without any problems. The subject reported that the overall workload was only a little higher than with the pick-by-light setup.

## 8.2 Pick-by-tablet

With exception of one subject (who feared that new technologies might negatively affect his future, causing a very negative attitude towards the use of pick-by-tablet), all subjects gave a neutral or positive response with regard to the use of pick-by-tablet. All subjects who also used pick-by-HMD preferred the tablet.

One subject noted that he prefers pick-by-tablet over pick-by-light. Another subject who initially showed a negative attitude towards pick-by-tablet, stated afterwards: *If I would have known that the system works so well, I would have taken part before. That system would be great at our big pick-by-light set. There you have to do 16 orders at once, and if your hand accidentally hits one active box the system switches to the next part without having the ability to go back to check the last step.*



### 8.3 Pick-by-paper

Every worker who used the paper pick list, mentioned quickly that it required much higher concentration and resulted in many more mistakes than with the other solutions. No one preferred to work with pick-by-paper, and soon everybody switched back to another method.

## 9. Discussion

Past studies focused on carefully-controlled, internally-valid studies comparing the speed and accuracy of various versions of mobile order picking systems to common practice (paper-based pick lists). However, such studies lack the ecological validity of testing on a manufacturing line with experienced employees fulfilling actual orders under time and accuracy constraints. In performing this study, we encountered all the challenges of introducing new technology to an established practice, including workers' initial reluctance to try wearable computing technologies (especially head mounted displays) in the place of a known system (pick-by-light). At first the company participants' reluctance to adopt new technology might seem disappointing when compared to the laboratory participants' acceptance in previous studies. Yet it underscores the importance of establishing a plan on how to introduce a new technology to a current process. Siewiorek et al. [10] provide a case study in how Motorola (Symbol) successfully introduced their wearable computer to similar industrial environments.

Overall user acceptance for pick-by-light and pick-by-tablet were quite positive whereas user acceptance for pick-by-HMD and pick-by-paper lagged far behind. Even after some workers tried pick-by-HMD, the approach had difficulties with user acceptance. Many workers reported – especially at the beginning – a higher workload and eye-strain. More experience with HMD usage and personalized fitting of the HMD to the individual worker's face may help offset these issues (for example, at least two workers were left eye dominant, which may have made seeing the display more difficult). Pick-by-paper, meanwhile, was discarded outright as causing too many errors. Pick-by-tablet, in contrast, was much better accepted directly from the beginning, and all workers – with exception of one worker – could imagine working with such a system.

With respect to error rate, pick-by-light, pick-by-HMD and pick-by-tablet perform very well. Pick-by-paper, in contrast, lags far behind the other methods. Pick-by-tablet and – even more – pick-by-HMD showed slower speeds than the established pick-by-light method

at the beginning. However, after some practice, workers' speed improved and was similar to pick-by-light.

Both pick-by-tablet and pick-by-HMD compare quite favorably to pick-by-light in terms of investment costs. All three methods virtually eliminate errors, even when pick detection was turned off, which was preferred by the users. Given the results here and in previous work [12], eliminating the pick detection system would seem to further lower cost, improve user acceptance, and have little effect on the pick quality. In contrast, a put detection system on the pick-cart could be implemented with a much smaller investment and allow – beside a reduction of errors (of the type putting/placing into a wrong order bin) – for an automated transition to the next pick-step when the previous pick-step is finished. Workers definitely desired this latter feature. Lights under the order bins (put-to-light) might also be a useful extension with little increase to investment costs.

For picking sets with a high throughput, the higher investment costs of a pick-by-light system might pay off compared to pick-by-tablet. However, with pick-by-tablet being much cheaper (regarding the investment costs) than pick-by-light and performing nearly as good in all aspects as pick-by-light (and much better than pick-by-paper), pick-by-tablet may more often be cost beneficial as compared to a pick-by-light system or to pick-by-paper (having a low or medium throughput).

While pick-by-tablet showed much better user acceptance in this study than pick-by-HMD, we still think that pick-by-HMD could make sense in cases where a tablet PC could not be mounted on a pick-cart. For further evaluations under real working conditions, the wearable solution should be optimized for an increased user acceptance by reducing size and weight. Afterwards, a further study with subjects using the wearable pick-by-HMD solution over a longer period should be undertaken. Another method to be considered for this study is a wrist worn device.

## 10. Conclusion

While we see potential for pick-by-HMD under circumstances where a tablet PC / mobile display could not be used on a pick-chart, we highly suggest further investigations regarding user acceptance and workload (especially eye-strain) for pick-by-HMD.

By contrast, pick-by-tablet was well accepted and also showed a good performance with respect to errors and speed. A key for this encouraging result is the pick-chart which allows for a quick and reliable recognition of what to pick and where to put. Pick-by-tablet (using the pick-chart) has, in our opinion, high potential to

be used at many picking lines where currently pick-by-paper is used and where an investment for a pick-by-light solution was not – from a business point of view – economical.

## 11. Acknowledgments

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# Developing a Wearable Computing Platform for Industrial Augmented Reality Applications

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## Abstract

Developing an industrial-grade wearable computer system has to be a tradeoff between ruggedness and battery runtime vs. weight as well as between performance vs. battery runtime. This struggle kept the development of high-performance wearables at low pace so far, which might now change with the advancement of smartphones as versatile mobile computing platform. The following is a summary of the *authors' development experience over the last decade* and current efforts in developing Augmented Reality (AR) capable wearable systems.

## 1. Introduction

During the last decade, the authors have been involved in many wearable computing projects, some academic research some commercial projects, but all of them with a clear focus on the application of wearable computer systems in industrial “real-world” settings. In the following, we will give an overview of the significant steps in these developments and an attempt of analyzing the status-quo of commercial industrial wearable computer systems.

## 1. Background

From the early beginning, we conducted wearable computing R&D with the industrial end user in mind. In the SCWC project in 2002, Carnegie Mellon University and Bosch Corporation developed two generations of a speech-controlled wearable computer system supporting vehicle technicians: one based on commercial-of-the-shelf components and a second as a

system completely from scratch [1]. Back then, introducing a commercial product of such a wearable system seemed too innovative for and was refused by the automotive aftermarket and thus, we could not transfer the research results of this collaboration [2] to the market. Although field-tests with actual vehicle technicians proved the applicability and the second generation hardware proved the possibility of a low-cost hardware system.

In our time at Xybernaut GmbH – the Germany-based European R&D office of Xybernaut Corporation, we supported a lot of pilot projects in wearable computing, mostly in collaboration with universities. One of the challenges was the performance, which many of the developers asked for. The well-known “laptop in a backpack” was (and is) always the reference for such systems; but performance is always a limiting factor in wearable systems design due to design constraints for wearable systems, such as smallest form factor with industrial-grade ruggedness and long battery life. Thus, in the last few years, speech recognition to us was the most advanced hands-free interaction for such wearable systems and the focus of research and development in those times [3]. This as well is one reason for the success of pick-by-voice solutions – completely audio-based systems with no display [4][5]. These systems are the only wearable computing systems so far with significant impact in industrial applications.

Meanwhile, one of the authors left Xybernaut to join a start-up company, which developed wearable systems for remote service technicians. The i-boro (see Image 1) was a task-specific device, which was developed with the help and feedback of customers [6].



**Image 1: i-boro wearable PC for remote service technicians**

Although i-boro sold for quite some time, the market was not enough for a sustainable business model for a company. teXXmo picked up this application idea and serves this niche market with a specialized wearable computing platform for these customers [7].

## 2. Current system development

Our current R&D effort bases on a research project conducted together with Daimler AG, SAP AG and University of Bremen [8][9]. In this project, we developed a demonstration of a small, light-weight wearable computer system, based on an X86 platform. We designed all interfaces as USB connections to have the best flexibility for testing several scenarios. Based on the experience in this project, we developed a commercial system with industrial connectors and buttons and a housing, which has an IP rating of up to IP65 (see Image 2).



**Image 2 – teXXmo ONE wearable computer system**

The system has a three-layer architecture, comprising of a CPU board, a base board and an interface board. Thus, the system is adaptable and can offer higher performance with the advance of CPU boards and can be adapted to different input and output demands by changing the interface board (Image 3).



**Image 3 – teXXmo ONE three-layer architecture**

teXXmo decided not to develop an own head-mounted display (HMD), but instead defined specifications for a monocular HMD with audio support and integrated camera, which teXXmo can retrieve from different manufacturers. The market for HMDs is still not yet advanced, neither for industrial, nor for consumer-grade HMDs.

Thus, in terms of usability, availability and price structure, there is a lot of potential in the HMD market. Therefore, several manufacturers, such as Liteye, Vuzix, Lumus, Laster, Trivisio, and Cybermind are working on rugged or semi-rugged HMDs. There are some large players from the consumer electronics business, who also try out HMD concepts – rather for use at home and on trains and busses: Sony, Brother, Zeiss etc. And we see some concepts of Google [10] and Apple, who might be able to attract an even larger customer base on the consumer market.

## 3. Augmented Reality on mobile devices

When we started the development of the current platform, it was not foreseeable that the development of AR engines for mobile devices would become that fast. This rapid development was boosted mostly by the widespread introduction of smartphones with high-quality cameras. In parallel, these smartphones follow the development cycles of former mobile phones and increase functionality and performance with every generation in very short periods. Thus, we see a new kind of mobile platform with enormous capability for AR applications.

Hence, AR engine manufacturers, such as metaio, Total Immersion or String Labs, offer AR solutions for smartphones and consumer Tablet PCs. Besides mobile usage scenarios, AR engines as well support browser-based applications used at the desktop computer at home or in advertisement kiosks in shops. Finally, there

are some approaches to use AR in engineering and maintenance scenarios, in which the tracking needs to be very exact.

#### 4. Future steps towards wearable AR

With the advancement of commercial mobile AR engines, we now have the possibility to introduce a new kind of hands-free interface for wearable computers to the market. The transfer of technologies from the consumer market to a more specialized, industrial market has been successful before, e.g. with PDAs being used for data collection. We will soon implement a new CPU board to our wearable platform, which provides more processing and graphics power to better support AR applications. Also, we are in touch with HMD manufacturers to connect directly to our wearable unit – without the extra control box, we often see with such displays. Besides these hardware developments, we are looking for new AR-based applications and started collaboration on different scenarios. The following two are probably the most obvious and will be our basis for further discussions with customers and academic partners.

##### 4.1 AR-based picking

As stated above, voice-based picking is well introduced and reduced picking errors in many real-world implementations for years now. To even further reduce errors and to facilitate complex picking tasks and especially navigation in complex warehouse settings, AR-based picking is topic of academic research, e.g. [9][11]. teXXmo supports first steps of commercially introducing such AR-based picking solutions to the market.

##### 4.2 AR-based tele service

In another project, we looked into AR-based tele service. Building on standard tele service scenarios, which offer live video and audio stream, the idea is to provide a mechanism, which enables an engineer at a help desk to activate AR content at the remote wearable tele service platform (see Image 4). A similar approach was taken by Fraunhofer FKIE with smartphones as mobile device [12].

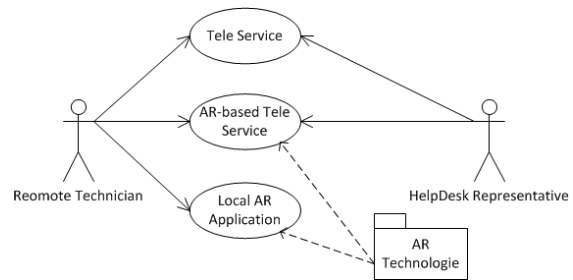


Image 4 – AR-based tele service

#### 5. Outlook

This paper gave a brief overview on the authors' development effort over the last ten years. We experienced academic research on (industrial) wearable computing and as well faced the challenges of building up a market, representing hardware manufacturers of different sizes. Current developments of big players such as Apple or Google [12] might help to broaden the idea of wearable computing and familiarize possible users with head-mounted displays; this happened with mobile phones and wireless Bluetooth headsets before.

At teXXmo we will continue to do research on wearable computing hardware and on software for mobile and wearable use. We will further facilitate discussions with academic and industrial partners and collect and provide as much information as possible to open up a market - or approach a market, which might be opened by other drivers of wearable computing.

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# Testing Mixed Reality for an Application in Order Picking

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## 1. Abstract

Driven by competition, innovation counts as the economic foundation for the progression of the modern industrial society. The innovative speed is often determined by the fast and efficient implementation of new technologies.

These progresses often seem to be of strategic importance, yet the successful implementation of the new technologies is still missing. For example, the RFID<sup>1</sup>-technology created hype in the 1990's though there still are not many economic applications for it today.

One of the reasons is the lack of a useful concept for the identification and analysis of the optimal implementation of new technologies in the beginning when the influence on the development is still high.

The question is how this gap can be filled. Which approach has to be used in order to graze the potential for optimization methodically and effectively in the early stages of a technological implementation, so as to make the most of the still high influence on the further development?

One field for the proper evaluation of such a methodical approach for the implementation of new technologies is the process of order picking. Apart from a classical procedure using paper, several systems to enhance order collating have been developed.

Mixed Reality<sup>2</sup> is the new technology to be applied to order picking by enhancing the optical sense with computer generated information in real time (Azuma, A Survey of Augmented Reality, 1997, p. 355f). Several universities (Günthner, Blomeyer, Reif, & Schedlbauer, Pick by Vision - Augmented Reality unterstützte Kommissionierung (Pick by Vision - an Augmented Reality Based Consignment System), 2009, p. 212ff) and institutes (Tümmler, Grubert, & Mecke, Nutzerbezogene Entwicklung und Untersuchung mobiler AR-basierter Werkerassistenzsysteme (Customer Related Development and Analysis of Mobile and AR-based Assistance), 2009, p. 74f) (Ehmann, Pick by Vision: Development of an Order Picking System Based on Augmented Reality, 2008, p. 2ff) are already on the point of launching their prototypes and developing successors.

Their methodical approach in coping with the effective implementation serves as a practical example and the pending development of a similar system at the Munich University of Applied Sciences can serve as an evaluation of the derived methodology. Keeping this in mind, the first step is the evaluation of the technology MR in its first, prototypal status in a field experiment to draw conclusions of its suitability for any further implementation.

Keywords – Diffusion of Innovations, Augmented Reality, Mixed Reality, Order Picking

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<sup>1</sup> Radio Frequency Identification

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<sup>2</sup> Mixed Reality is a blend of the real environment and virtual objects projected to the user; abbreviated as MR in the following

## 2. Theoretical Background

This chapter is giving a short overview over the three main topics of the research field. These are MR as the technology in question for the implementation, logistics, especially warehousing as the area of implementation, and are innovations management, bringing them together in an industrial application.

### 2.1 Mixed Reality

One technology offering promising features is MR as it has already been tested in several production processes. MR is the enhancement of the optical sense with computer generated information in real time (Azuma, A Survey of Augmented Reality, 1997, p. 355f). It is a blend of the real environment and virtual objects projected to the user as can be seen in the following figure:

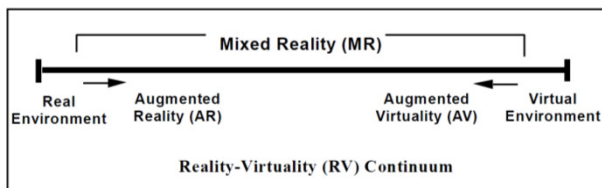


Fig. 1: Simplified representation of a RV Continuum according to Milgram (Milgram & Colquhon, 1994, S. 283)

It can be seen in figure one, that the often referred to Augmented Reality is much more focused on the direction to the real environment. As there is no conclusion now, to what intensity virtually enhanced reality is applicable best, the much broader definition of MR is used in this paper.

Adapted to the area of logistics for the application, the worker gets special glasses with displays that provide him with context related and helpful information. This allows him to focus on the main work, picking and packaging.

The following figure two shows a possible example with a visualised pick list:



Fig. 2: Scheme of a worker with visualised pick list

It is the aim to implement the system at low costs in order to provide an efficient and affordable solution.

#### 2.1.1 Current State of Research

There are already prototypal applications for MR-technology in many areas, e.g. medicine (Lievin & Keeve, 2001, S. 10f), military (Tappert, et al., 2001, S. 625ff), architecture (Tamura, Yamamoto, & Katayama, 1999, S. 62f) and production (Azuma, Baillot, Behringer, Feiner, Julier, & MacIntyre, 2001, S. 35f) (Mizell, 2001, S. 447ff), just to name a few.

In any case, four main questions have to be discussed for the implementation of MR for order picking:

- display unit
- tracking system
- information representation
- procedural influence (Alt, 2003, S. 21)

#### 2.1.2 Display Unit

There are basically four methods of displaying mixed reality images, classified by two characteristics.

First it offers the possibility of looking around, i.e. the viewer is not connected to the display, or looking through, i.e. the display is attached to the user and his field of vision.



Secondly the question of whether the field of vision is enhanced by virtual insertions (OST<sup>3</sup>) or whether the real and virtual images are premixed and displayed as one picture (VST<sup>4</sup>) arises.

Figure three shows the four different types of visual overlays.

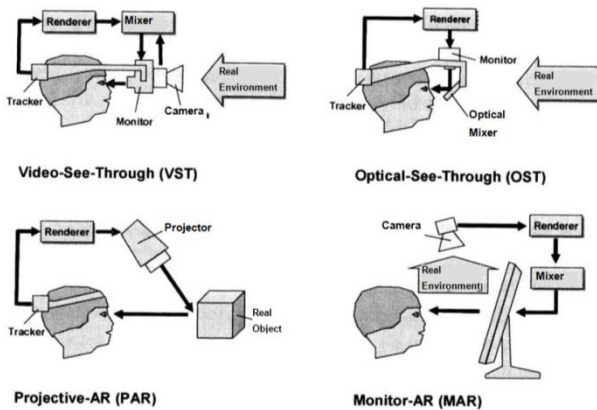


Fig. 3: Different methods of visual overlays (Patron, 2004, S. 24)

### 2.1.3 Tracking System

In order to provide context-based visualisation, the position and direction of the user have to be identified and tracked. The assessment of the tracking system includes degrees of freedom, accuracy, latency, robustness, room of measuring and price (Alt, 2003, S. 74ff).

Excluding the Global Positioning System (GPS), as it is simply not working indoors, there are the following possibilities:

Using mechanical tracking, the user's display device is attached to arms and joints equipped with sensors which gauge the movement/alteration (Müller, 2001, S. 498f). This method is very accurate but involves high costs and limited mobility.

Another possible way is to use an electro-magnetic field. The user wears a sensor that measures the field intensity and determines the position. Its advantages are its small size, little latency and low cost. However, the diverting influence that metallic objects have on the

magnetic field, limits the operational possibilities within industrial environments (Ascension Technology Corp., 2008, S. [www.ascension-tech.com/products/index.php](http://www.ascension-tech.com/products/index.php)).

The optical tracking, using cameras, offers two solutions. Either outside-in, where the cameras are installed in the room (Livingston, 1998) and tracking markers are fixed to the user, or inside-out where the user is wearing the camera and tracking different markers to locate his position (Kato & Billinghurst, 1999, S. 86ff). Fair accuracy is confronted with high costs for commercial solutions.

Inertial tracking measures acceleration of gyroscopes and by single (velocity) or double (position) integration provides the necessary information (Müller, 2001, S. 499). This system is small and shielded from environmental influences but relatively inaccurate.

Other outsider tracking systems make use of acoustics, laser or a mini-indoor-GPS (Müller, 2001, S. 499).

### 2.1.4 Information Representation

The form of visualised information in MR systems is open to any style the operator chooses. They may consist of static or dynamic insertions, text, pictures or 3D-models. Different kinds were already tested in past applications:

- ID-Nr.
- position oriented text
- animation: blinking
- animation: frame
- animation: colour (Alt, 2003, S. 62f)

Depending on the individual case, the visualisation may be context-sensitive and congruent (Alt, 2003, S. 48).

In order to provide a spatial perception, monoscopic techniques like the constancy of size or the overlapping of objects as well as the parallax of movement can be employed (Frisby, 1997). Even better results can be yielded with a real stereoscopic view. In order to create the effect, the images for the right and left eye have a slight offset depending on their virtual distance. The closer the object the bigger is the offset. But as every eye only perceives its own image, the displacement is recorded as depth. This natural awareness of stereoscopy is represents a much lesser strain for the users mind of the user (Klein, 2008, S. [www.stereoscopy.com/faq/computer-stereo.html](http://www.stereoscopy.com/faq/computer-stereo.html)).

<sup>3</sup> i.e. Optical See Through

<sup>4</sup> i.e. Video See Through

### 2.1.5 Procedural Influence

In order to evaluate the effect of MR enhanced processes, quality and time have to be measured.

In one recorded test, the needed time for the assembly of plane parts could be halved (Mizell, 2001). In another test the time for an experimental automotive assembly step could be reduced from 24s to 11s, the recall ratio rose from 94% to 98% (Alt, 2003, S. 88f). The study further identified the dependence of effective MR systems on the complexity of an application.

Only after a specific bound of complexity, the use of MR is of help to the operator and therefore contributes to the reduction of necessary time for the process as can be seen in figure four:

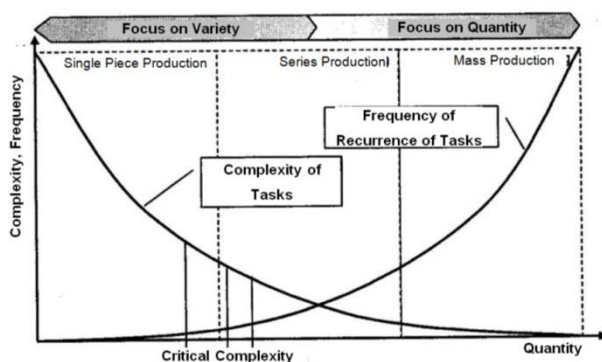


Fig. 4: Critical complexity for the use of MR technology (Alt, 2003, S. 100)

## 2.2 Logistics, Warehousing, Order Picking

Conditions in the field of logistics have changed rapidly over the last years. Customers are demanding more individualised products in even shorter delivery time. Production Systems and the logistics material and information flow, as well as the workers within these systems, have to become more flexible, faster and of course more efficient (Reif & Walch, 2008, S. 987). One of the most important processes in logistics is order picking. Order picking is the gathering of goods out of a prepared range of items following some customer orders (Gudehus & Kotzab, Logistics. A Handbook: Principles, Strategies, Operations, 2007). As it is no value-added process costs arising from this handling of goods are especially in focus to be reduced (Ehmann & Kaiser, Auswahl von Kommissionierverfahren (Choosing Consignment Systems), 2009, S. 19). Due to the high variety of goods in order picking applications, machines cannot usually replace the human-being with his flexibility and fine motor skills (Gudehus & Kotzab,

Logistics. A Handbook: Principles, Strategies, Operations, 2007).

Being part of the supply chain, the process of order collating is still dominated by manual operation. As this concerns more or less C-parts with a low value, the need to reduce costs is of great importance and therefore the process has to be kept as brief as possible. This is even more important against the background of a demand for an increasing number of individual orders.

Beside the classic pick list, several systems to enhance order collating already exist, each with its pros and cons:

System	Pro	Contra
Barcode-Scanner	flexible additional tasks possible	hand occupation time-consuming navigation
Pick by Light	fast easy to learn hands free	serial order handling expensive installation limited to sections
Pick by Voice	flexible hands free	slow difficult communication

Table 1: Comparison of different consignment systems (Vogt, 1997, S. 81ff) (Gudehus, 2002, S. C2-71)

It is now the intention, to implement a new consignment system that functions without these disadvantages and at the same time enhances the process in several ways.

## 2.3 Innovations Management

Implementing new ideas is often difficult, even if they have obvious advantages. This process often requires a lengthy period of time. How to speed up this rate of diffusion is the main focus of Rogers' "Diffusion of Innovations" (Rogers, 2003, S. 1).

The process of diffusion can be compared to the product life cycle concerning the penetration of the market (see figure five).

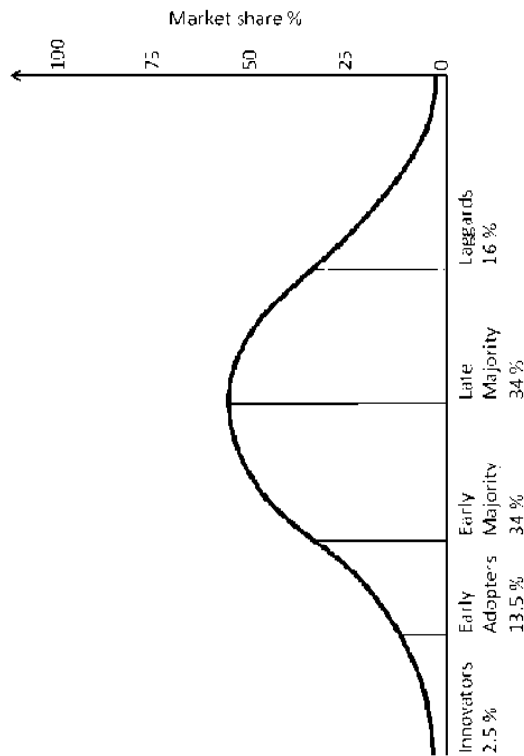


Fig. 5: The innovativeness dimension (Rogers, 2003, S. 281)

Rogers is stating that new innovations and products undergo a rise in market share from their introduction to the first buyers (which means users of a technology in this case). This is followed by a saturation of the market when the majority is making use of the technology and only rounded off by the laggards. Mixed Reality in Order Picking is still in the innovators phase without a measurable market share.

It is mainly focusing on the temporal sequence of innovation acceptance (Rogers, 2003, S. XV):

- **Knowledge** of the technology
- **Persuasion** of the client/customer to make first use if the technology
- **Decision** after the first use whether the technology and its benefits are accepted or rejected
- **Implementation** of the technology in the applicable environment
- And finally **confirmation**, which may lead to further diffusion inside and outside the company.

Since there are now industrial applications of MR in the logistics area up to this date (further than prototypal experiments) the innovation in this case should be somewhere between stage one to three of the acceptance process. The actual stage has to be verified in the upcoming approach in order to measure to what extent influence can still be made.

This model therefore may be applied in order to determine the status of acceptance of a technology.

Defining the phase and stage of a technology's status in the innovations lifecycle, prepares for the afterwards following methodological approach in influencing the abilities of MR in applications in order picking.

One similar problem was discussed by Resch in relation to the implementation of RFID-tags. This technology created hype in the 1990's due to its promoted possibilities in assisting the information flow in supply chains. Nevertheless, there are still not many implementations in the companies.

Resch described this as the missing gap (Resch, 2006, S. 5). He states, that most of the future project costs for the implementation of a technology are set in the beginning. Also the decisions made at the start influence greatly what and how much of the potential of the innovation is going to be realised.

On the other hand, there's no methodical safeguard to graze the full potential and understand the technology's best way of application right from the beginning.

Evaluation of the triggering criteria of a technology's possibilities has to have two perspectives:

Firstly, what can the technology provide? Meaning, what are the advantages of it compared to the existing and already used older techniques. This was related to in chapter 2.1.

Secondly, what do the users and decision makers for the implementation want to get by risking to implement this new technology.

One theoretical model, assisting the second point of view, is discussed in the following.

Scientists in the area of management information systems often rely on theories from social and psychological sciences. Thereby the theoretical basics were applied to specific situations of a computer based use of information systems (Resch, 2006, S. 132). For

the first time, Davis described it as Technology Acceptance Model<sup>5</sup> in his report “Perceived Usefulness, Perceived Ease of Use and User Acceptance of Information Technology” in 1989 (Davis, 1989).

In contrast to the diffusion of innovations model, the TAM is focusing on the causal parameters for decision making and not the timeline of the decision process. Nevertheless it has experienced several adjustments and derivations as well.

An adaptation of the TAM for complex technologies can be seen in figure six.

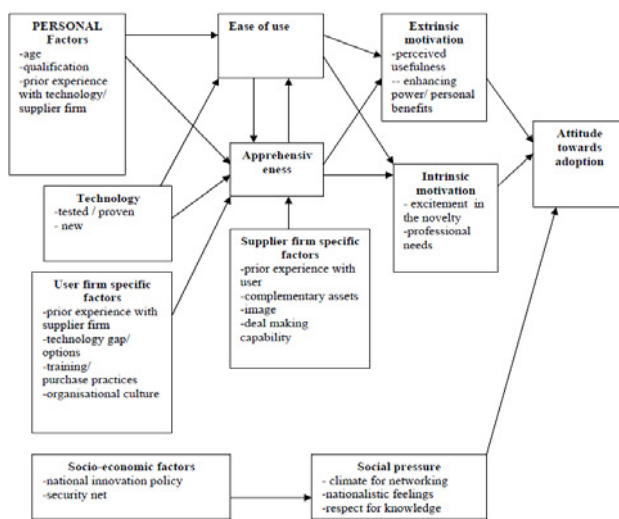


Fig. 6: Adaptation of the TAM for complex technologies (Rao, 2004, S. 8)

It mentions different aspects of a technology as triggers for the decision of an individual of accepting or rejecting it. According to Rao, the four main influencing parameters are apprehensiveness, ease of use of the technology and extrinsic and intrinsic motivation.

Which parameters are relevant in this particular case, has to be elaborated, once MR has proved to be a competitive technology to the existing techniques in order picking.

### 3. Derivations and First Test in Order Picking

With the background from the three areas innovations management, MR and warehousing a first field experiment was prepared and as well performance characteristics as personal feedback was gathered.

The goal of the field test was to see, whether MR is even applicable for order picking or not. This should show if the users can work ergonomically with the equipment needed for the prototype, if they are accepting a new, innovative technology and are the decision makers willing to get to know this possibility.

To gather firsthand experience and evaluate the first reactions caused by the implementation of an mixed reality system in a logistic environment, a very basic prototype for order picking was assembled and tested with an industrial partner.

The prototype consists of a pocket computer connected to the warehouse management system of the partners warehouse, a head mounted display for the visualisation of the order data and a key-pad for basic interaction. The prototype can be seen in the following figure seven:



Fig. 7: Prototypal order picking with a head mounted display

Three workers of different age used the prototype for several weeks. During that time the performance was measured (see table two). The decline in concentration was measured before and after work. The workers were

<sup>5</sup> abbreviated as TAM in the following

furthermore requested to fill in a feedback form, partly guided and partly with open sections.

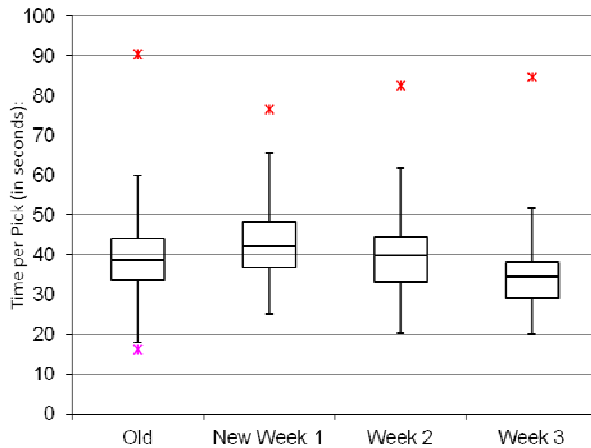


Table 2: Distribution of the picking time as output of the field test

Week zero displays the distribution before the implementation of the prototype. Weeks one to three state the progression after the implementation. Using a box and whisker chart makes it possible to evaluate the progression as well as the distribution of the measured picking time on the timeline. As can be seen the median is declining and the spread of the distribution is being reduced. The decreasing median is showing, that the picking is processed quicker, being already ten percent faster than the old method in week three. The worker seems to get used to the tool and understand its advantages for his task. Implementations of other pick assisting technologies show, that a saturation of this learning curve is to be expected two to three months after introduction.

The distribution of the pick times is reduced as well. This may be due to the stabilization of the process. Lesser outliers may result from more routine for the worker during his task and therefore less unexpected problems while working.

The field experiment provided two main outcomes. Firstly mixed reality can make a difference in performance. To what extent and under what circumstance remains undetected.

Secondly there is a great influence from both, the user of the technology and the decision maker for the implementation. The influencing factors and their proper adjustment remain unclear so far as well.

## 4. Conclusion

Driven by competition, companies try to implement new technological innovations in industrial applications in order to gain advantages over their competitors. These three fields are backed up theoretically and on the applied side filled with MR (innovation), logistics/warehousing (application) and the visual guided order picking system as junction.

As there are already technical but not economic applications in this area, the further research focuses on the evaluation of key parameters for the successful implementation of this innovation and the relevant characteristics of its application.

A first field test was prepared and executed to gather first reactions from the users and evaluate the applicability of MR in order picking. The outcome was positive. Any further field experiments should be prepared with the triggers and factors to be evaluated in mind.

These aspects have to be elaborated and discussed with the decision makers of such applications with guidance from existing models for innovations management.

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# A Discussion of Precise Interaction for Wearable Augmented Reality Systems

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## Abstract

*In this paper, we discuss the research topic of precise interaction for Wearable Augmented Reality (AR). Our research focus is towards improving interaction with wearable AR systems to assist in the creation and modification of user contents. We present a set of techniques that supports both the creation and modification of virtual models for outdoor wearable AR. Based on our experience, we discuss several challenges faced during our research, in order to emphasize the focus on solving the problem of precise manipulation through the development of new interaction techniques and input devices. We believe that precision is an important problem to tackle for the industrialization of wearable AR.*

## 1. Introduction

Our research into Wearable Augmented Reality (AR) has been focusing on user interaction with virtual contents, especially applicable to large scaled objects, such as buildings and street furniture in outdoor environment. In this paper, we discuss the challenges we have faced in our research as well as propose approaches to the problems of interaction in Wearable AR, in the context of industrialization for Wearable AR.

Industrialization of Wearable AR requires mainstream hardware. For immersive AR, there have been various consumer-ready products, such as the range of video eyewear by Vuzix<sup>1</sup>. Cakmakci and Rolland [1] outline the challenges of head mounted display (HMD) research in a comprehensive review of the technology. Development for HMD is actively ongoing within the industry. Wearable computer platforms are not as popular, with the main drive of development towards mobile and portable devices. The wearable computer research community regards the mobile phone as the most successful wearable

computer to date. However, AR related applications for mobile phone are not widely adopted (There is no AR-related app on the lists of Top 100 free and paid apps on Android<sup>2</sup>, the most popular smartphone platform in the US [2]).

Apart from the hardware challenges, social [3], psychophysical [4], and design [5] factors also affect the widespread adoption of Wearable systems. Our research is focused on the user interaction to the system, because we believe that enhancing the user experience with wearable computer systems will improve the adoption rate of the technology. As can be seen from the popularity growth of the mobile phones, one of the factors that propelled mobile devices into ubiquity is the advancement of touch screen technology, which brings natural and user friendly interaction to the mass [6].

In this paper, we present our general research approach for interaction for wearables, which is focused on the creation, modeling, and modification of virtual user contents. We also present a set of model refinement techniques, which assist in such a process. Moreover, we address the problem of precision interaction techniques to emphasize its importance in promoting a wide adoption of wearable AR technology.

## 2. User contents

AR is an interactive medium through which the real world environment is supplemented with virtual information. The main source of virtual information for AR is virtual models, co-located with the physical surroundings. Models play an important role in AR systems [7] to improve the AR experience by supporting the algorithms that provide improved occlusion effects [8] and more accurate tracking and registration [9], as well as augmenting the corresponding physical objects. There are several non-AR techniques for creating models; however, they lack

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<sup>1</sup> [www.vuzix.com](http://www.vuzix.com)

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<sup>2</sup> <https://play.google.com>



the instantaneous contextual information offered by AR systems, which leads to a time-consuming modeling process. In-situation modeling is conducted while both virtual and physical world contents are in the AR view, thus providing a live feedback to the modeling process. Modeling on Wearable AR system enables the users to create and modify their own contents, which provides higher engagement of the users to AR systems. Our research into AR interaction is focused in this direction. We are driven to facilitate the process of user contents being created and modified on the fly.

Unlike traditional desktop-based systems whose input devices such as mouse and keyboard are fully developed, AR systems, especially wearable outdoor ones, do not have a similar range of versatile input devices and interaction techniques to support complex and precise modeling tasks. We have surveyed many approaches for modeling using wearable AR systems, including systems by Baillot et al. [10] and Piekarski & Thomas [11] using wearable computers, and by Langlots et al. [12] and Simon [13] using handheld devices and video cameras. We have discovered that the majority of the techniques only produce simple textured polyhedral models of outdoor structures. The surface details of the structures are often captured as 2D texture images instead of being properly modeled in full 3D. Therefore, we are interested in a model refinement process in which extra surface details are created and added to existing models that are created by other AR and non-AR techniques. The next section describes our research work into a set of techniques for model refinement for wearable AR systems.

### 3. Model refinement techniques

Our methods support model refinement with two main techniques, namely the *augmented rangefinder* and the *augmented viewport*. The augmented rangefinder technique [14] employs a hand-held orientation tracked single-point laser rangefinder for sampling corner points of a physical object. Using this approach the physical object can be either convex or concave and a matching triangular mesh is generated with the same geometry as the physical object, as illustrated in Figure 1. This technique is useful for the *addition* of surface features on existing textured polyhedral building models, or to correct the errors caused by occlusions in the LIDAR models.

The augmented viewport technique [15] utilizes physical cameras in the environment to create a window view into a distant location, through which the user can perform precise manipulation on models at a distance. This technique assists in the model

refinement process by enabling *adjustment* transformations such as translation, rotation, and scaling of the whole or parts of the virtual model to increase the matching accuracy in the positions, orientations, and sizes between the model and the physical object. Figure 2 shows two viewport windows from two cameras pointing to the same remote location. The viewport windows display the top of a physical window and a virtual window lintel (in red)

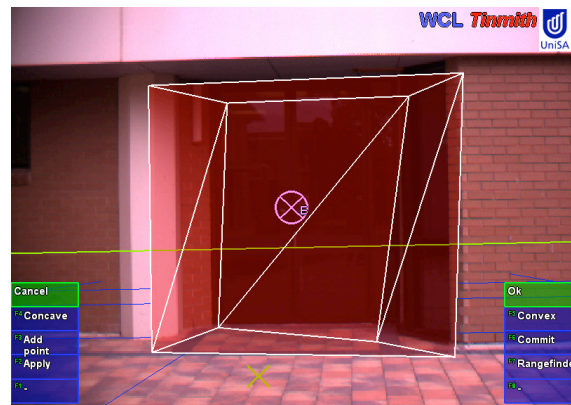


Figure 1. A model created by the augmented rangefinder technique



Figure 2. Multiple augmented viewport windows

### 4. Precision in interaction

Based on the experience of our previous work with interaction techniques for outdoor wearable AR systems, we raise the focus of interaction research on precise modeling and manipulation for wearable AR systems. The users of wearable AR system require the ability to create and modify complex and precise virtual objects in context. Therefore, precision is an important factor to consider for interaction research. We have found several challenges during our research.

It is a common approach to apply Virtual Reality (VR) interaction techniques into AR systems. However, most of VR interaction techniques are design to be effective in an immersive virtual environment, in which the user has a pure virtual presence, represented by an avatar. The virtual avatar is not constrained by the physical environment, enabling the user to perform such actions as flying, extending hands, or teleporting. This is not possible in AR systems. Moreover, VR interaction techniques have been known to exploit the human's proprioception, the perception of the locations of body parts in space, to assist with direct manipulations of virtual objects [16]. Being unable to visually perceive the location of their real hands in an immersive environment, the user could only rely on their proprioception to perform interactions. Where there is a sensory conflict, visual information often dominates proprioception [17] and it has been shown that human are less sensitive to the conflict between the vision and proprioception when the virtual hand is separated from the position of the real hand [18]. Therefore, such techniques that separate the position of the virtual hand from the real hand could be effective in an immersive environment. In AR systems, both the real world and virtual information are visually perceived. Therefore, an implementation of the arm extension technique, for example, for outdoor AR would introduce a conflict in which both the physical and virtual hands are visible. It is expected that the hand extension techniques, would not be effective in outdoor AR due to the visual information conflict. A new model of virtual hand interaction is required, in order to provide an intuitive interaction method for wearable computer users.

Furthermore, wearable AR systems are often set in an outdoor environment, where objects are often placed at a large distance from the user. Precision in manipulation is inherently low in action at a distance. Errors are traditionally caused by free hand operation [19] or sensors during manipulation tasks, which are accentuated at distances. Small movements of the user's hands or input device are translated to greater displacement of virtual objects at a distance; thus severely diminishing the precision of the operations. Unlike indoor systems, wearable systems are directly worn on body by the users, thus requiring certain constraints on the physical body. Complex indoors system has the freedom of infrastructure, which allows great precision, such as the tracking systems by OptiTrack<sup>3</sup> and Vicon<sup>4</sup>. Therefore, designing interactions for wearable computer imposes certain

constraints on the infrastructure of the technology used.

## 5. Conclusion

In conclusion, we believe that for a successful track on industrialization of wearable AR systems, precision is required to be dealt with as an important research challenge. Based on our experience and previous works, precision is not only improved on the hardware, sensor developments, but can also be enhanced by directly focusing on interaction techniques and novel input devices.

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# A Heuristic Approach to Robust Laser Range Finder based Pick Detection

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## Abstract

*The common approach of reporting picks when a laser range finder detects an object inside a predefined area has some problems. Pickers might accidentally trigger an action by reaching into a bin in a crooked angle or by getting part of their clothing into the invisible laser beam. Also larger objects may reach out of their bins and into the field of the scanner making the defined region unusable for pick detection or even cause false picking events. Using a heuristic approach to interpret the observed data makes it possible to derive a simple algorithm to only trigger a picking event for 'hand/arm-like' objects in the field. This process only adds a small latency to the system while improving the usability.*

## 1. Introduction

Order picking is the process of collecting items from an assortment in inventory and represents one of the main activities performed in warehouses. It accounts for 55% [1] to 65% [2] of the total operational costs of a warehouse. According to an estimate by de Koster et al. [3], 80% of the warehouses in Western Europe are picked manually from storage racks or bins (low-level picking), where the picker moves among the parts (picker-to-parts) and picks multiple objects based on a particular order. In many cases, workers use a computer generated text-based *pick list* which simply lists the parts to pick and their locations for a given order. Common optimizations on this process include *pick by light* where a computer controls lights mounted on shelves to indicate from which part bin to pick and *pick by voice* where the worker wears a computer that announces which parts to pick.

While the most important part of the picking process is providing the picker with information on the parts to pick, also the detection of picks is of relevance. For correct picks an IT system can keep track of the task progress while for incorrect picking events feedback to the picker can be gen-

erated. Pick detection can be as simple as having the picker press a button to indicate the action, installing light-barriers at appropriate places or using a laser range finder to observe a whole shelf.

While the first two options are very robust and accurate they scale not so well with large shelf systems. In both cases each component has to be mounted and wired for every location where detection is needed increasing costs and maintenance. The third option of using laser range finders allows for flexibility as the observed area can be partitioned to detect picks for multiple locations. Only a few LRF have to be installed and maintained to cover a high amount of locations and if the arrangement of the locations changes only a change in the partitioning is necessary.

There are however two prominent downsides of this approach. A LRF can only observe objects that penetrate a flat curtain of light and requires that all locations are below it. An other issue is the accuracy of these systems which changes along with the distance and the surface of the objects to detect.

A conservative approach to the latter problem is choosing *dead-zones* around locations where detected objects are simply ignored. This can however be problematic when a pick occurs at a crooked angle resulting in a penetration of the light-curtain partially outside the location or even partially inside another location.

Dealing with these cases is important for user acceptance especially when a false negative occurs (a correct pick that is detected as being wrong) where user frustration may set in.

## 2. Heuristic Pick Recognition

### 2.1. Object Detection

A LRF does not detect objects on its own but merely reports the distance at which a beam of infrared light was reflected by a surface (or the absence of a reflection). A laser beam is rotated to produce a curtain of light and a measurement is taken at fixed angles relative to the scanner. The

quality of the resulting contour of a detected object is therefore limited by the angular resolution of the scanner and degenerates with increasing distance. It is also noteworthy that an object detected by the LRF produces a *shadow* behind it where no other object can be detected.

The detection process works best with diffuse reflecting surfaces and does not work for materials that deflect the beam like metal or glossy varnish. When working with the results from a LRF one also has to take into account that there is always noise in the measures distances which may increase with the distance to the object.

To actually detect an object out of a set of measured distances, sequences of distance values are interpreted as its contour. A software system needs to decide whether a gap between two measurements separates two objects or is just the result of measurement distortions. The parameters for making this decision need to depend on the distance of the object since a gap of one measurement is only a small distance on the surface of a near object but can become large after a few decimeters. See figure 1 for a graphical representation of the detection principle.

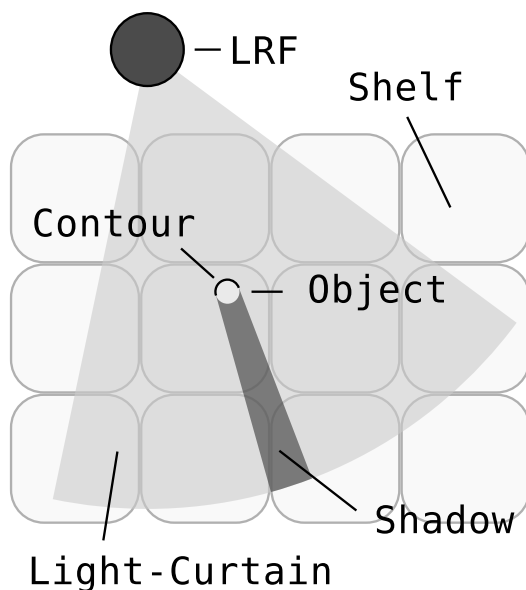


Figure 1. LRF detection principle

## 2.2. Characterising Measurement Groups

To be able to group a potentially fragmentary sequence of distance measurements to an object you need to define criteria for sorting out sequences that are unlikely to be of interest. In the case of picking we are interested in detecting the lower arm of the picker when entering the location of the part. It is safe to assume that the lower arm is either not covered with clothing or that the clothing is reasonably

fitting around the arm. Therefore it can be approximated to be cylindrical. Since the position of the LRF can vary between setups no assumption can be made on the angle from where the arm is detected for a general algorithm. If we take further into account that pickers may enter the locations at crooked angles we know that the detected surface will be circle-like in the optimal case or elliptical in most other cases.

## 2.3. The Bubble-Approach

When hands or arms enter the light curtain of the LRF the noise that accompanies the distances measurement is very high compared to the actual size of the object. Experience showed that trying to recognize the actual shape from the data is unreliable or at least computationally expensive but that a coarse interpretation of the data is sufficient for the goal of robust pick detection.

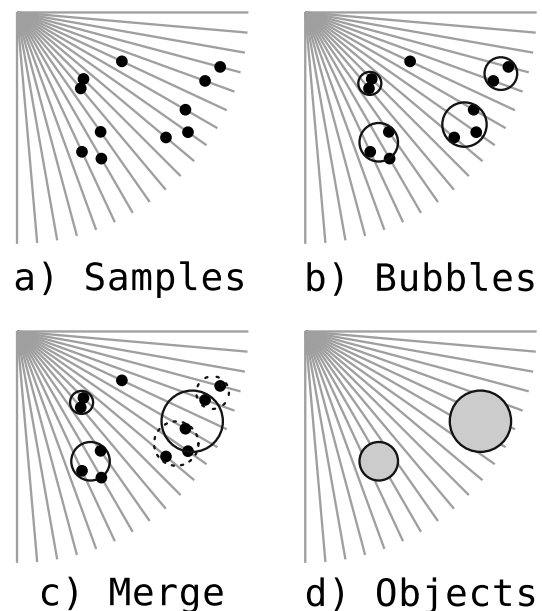


Figure 2. Bubble principle (simplified)

At a first step *continuous* distance samples from the LRF are grouped together. If a sample has hit an object all following samples are interpreted as belonging to the same object until a terminating sample occurs. This can be either a sample that indicates no hit or a sample that is farther away from the last sample than a predefined length. When such a continuous set of samples is completed a *bubble* is formed out of it. These bubbles are circular areas that represent the detected object. They are geometrically defined by using the first and last point from the sample set as opposing points on the border of the bubble. Point locations are simply derived from the distance and the technical specifica-

tions of the LRF. It is worth noting that these areas do not necessarily contain all points from set and are not meant to model the arm of the picker. In a pruning step bubbles that are too small or large to be an arm or hand are rejected. See figure 2 for a visual representation of the process.

Since the measured distances are often fragmented a single object will generate several bubbles normally. In an additional step neighbouring bubbles are merged resulting in fewer and bigger bubbles. While all initial bubbles will not overlap due to their construction this must not be the case in the merge step where each merge operation creates a bubble with a diameter that is larger than the two original diameters. The exact method of the merging process also depends on parameters that need to be chosen for a particular setup.

In addition to reducing the data to process, these objects can now be tracked over time by identifying the same bubble in two measurements. This enables observing individual hand movements inside the light curtain and can even support multiple pickers on a single shelf (within reasonable separation of picking locations).

#### 2.4. Increasing Robustness

One problem with using LRF for pick detection is handling static errors in the environment. One source of errors are objects outside of the shelf that are still reaching into the light curtain. These can be handled relatively easily by avoiding their location in the setup of the system. Another source of errors are objects that accidentally reach into the light curtain. These can be either bulky objects that are not stored deep enough in the shelf or longer objects that reach out of their individual box. Dealing with these objects is difficult with traditional approaches because these regions would need to be measured and marked dynamically.

Using the bubble idea a more convenient approach is possible. Since the objects in the light curtain will also generate bubbles, it is possible to take measurements for a few seconds without a picker on the set and store these bubbles as a reference to avoid these areas. In the above mentioned merging step this information can be used for further pruning.

Since this procedure is fast and in general non-critical it could be made available to unskilled workers via a simple button or similar input possibility. This would give the picker more control if the system starts to 'act strange'

which may increase the acceptance.

### 3. Future Work

One problem with this heuristic approach is finding correct values for the grouping-, merging- and rejection-process. Arms with dense hair-growth look different than non-hairy arms and also the choice of fabric for the clothing can have an impact on the received contour.

The additional use of wearable technology would make it possible to have the parameters for individual workers dynamically transmitted to the recognition system to increase the accuracy of the system.

### 4. Conclusion

Using the *bubble*-approach allows for a flexible system that can detect picking events while rejecting objects that are unlikely to be arms. Even in the case of accidentally placed objects that expose 'arm-like' characteristics to the scanner a robust and easy correction method exists.

The interpretation of measured data as physical objects allows for tracking their movement and can be used to map pick events to individual workers. This augmented information can be useful to the picker and also to IT systems that manage the picking process.

Initial experiments have shown that this heuristic method works reliable and avoids some problems of traditional LRF systems for pick detection.

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# Using gloves with sensors in industry

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## Abstract

*This paper describes possibilities to use gloves with sensors and actuators in an industrial context to have some kind of augmented reality and communication by use of gesture recognition and vibration feedback.*

## 1. Introduction

A sensor / actuator glove has the advantage that it is not a new device to its user because in many places in the industry gloves are already worn. So it has the advantage that it is not a new, separate item to be carried along, but just a part of the regular work-clothes that gained additional capabilities. Vibration is already known from cell phones and gestures are used as part of many workflows. So this might be a good combination as the individual concepts that make up the actual glove are in themselves all already known to the users. It is the combination into one functional whole that is the real novelty.

## 2. Related work

In the Glovenet project [1], a sensor network consisting of firefighter gloves was created. The gloves have a temperature sensor so that the firefighters can use it to check the temperature of doors and derive the conditions behind that door. They communicate with gestures and have feedback.

Experiments were also done with gloves for learning piano playing [2], which have vibration motors on every finger which are turned on according to the note to be played so that the piano player knows what to play. That is done as a replacement for exercises which have to be done as a result of injuries.

## 3. Examples of use

- **Steel cooking**  
Gestures can be used to control the opening and movements of the converters. The gloves as part of the protective clothes can hardly be forgotten. The radios of the gloves can help localizing the workers on the ground and thus help in preventing accidents by informing machines about the presence of humans around them, and by telling the handlers of moving machines about the presence of people especially when they can't see them visually. Warnings of moving machines can be transmitted by vibrations to accompany optical and acoustical signals.
- **Steering of big machines**  
Moving a heavy load to a given location on a construction site requires a lot of communication between the handler on the ground and the crane-controller. Gestures can be used to control the crane directly - like remote controls with a joystick can - as well as to assist only, such as stopping the cranes motions according to the stop-signal issued by the handler. That way the human delay in reaction can be reduced. In a hump-yard scenario gestures of the railroad worker trying to connect a train can complement and/or limit the train drivers actions, reducing the risk for the train worker by preventing any sudden movements of the train after he issued the 'move very slow' gesture.
- **Vehicle / Machine maintenance**  
Assembling large machines as well as maintenance of them can involve cranes and the moving of heavy components. This part is equal to the example of steel cooking as well as the general control of large machines. If controlled by a computer, parts of machines that need to be tested can be activated using a glove's gesture interface and it's radio, and feedback from the machines own sensors can be translated back to impulses for the gloves vibration interface, providing in-

formation if the part in question operates now within acceptable tolerances or still outside of them. Even the direction of the offset - if applicable - can be communicated via vibrations.

- **HazMat handling**

Hazardous materials have to be transported and stored, and handled with the proper care. Gloves equipped with sensors attuned to the relevant substances do not need to be carried along as individual items, but simply are part of the work-clothes. Touching an object which emits a dangerous substance (microfissures, leakage, spillage, radiation) will thus be recognized by the sensors and the worker can be warned. Utilizing variations in the vibrations or even issuing an emergency call the glove can provide enhanced work-safety for the worker as well as provide information about the degree of contamination. Levels exceeding safe work parameters would, for example, automatically send an emergency signal as well as require the worker to issues a special gesture to stop the alarm temporarily. Acceptable levels of contamination would only send a short pulse to tell the worker about the degree of contamination. By accumulating the amount of exposure the glove can also inform the worker when the safe overall level of exposure has been reached.

### 3.1 Possible vibrator output

Since the vibrator signals should be easily distinguishable, only a limited number of signals could be used. Steady and periodic ones might be a good idea. Maybe two different periodic signals can be used and they can be mixed, there are short period vibrations, long period vibrations and alternating short/long.

### 3.2 Gesture input

Using already-known gestures improves learning of the system. For steering big machines, people can use the same gestures as for communication with the driver. A gesture for switching the glove to gesture recognition mode may help to distinguish between common day movements and help to reduce processing power needed. Some accelerometers already have detection for some simple gestures like doing some double taps. Depending on the processing power available, gesture detection can be improved by using gyroscopes or magnetometers. With that, people can point in a certain direction for steering something. The possibility also depends on how much the earth magnet field is disturbed in the work environment.

**Table 1. Input / Output plans**

Input	when	Output
machine still ok	machine is touched by glove	periodic short
tapping the machine	technical problem	short-long
gesture from superior	emergency situation	steady
steering gesture	operating a machine	machine moves
battery low	activating glove	short-long pulses
emergency gesture	operating a machine	machine stops emergency call
emergency gesture	being near machines	all machines stop (emergency shutdown)

### 3.3 Interesting input sensors

- gas sensors
- temperature sensors
- radiation sensors

### 3.4 Input / Output plans

Table 1 shows an example plan for how such a glove can react.

## 4 Possible problems

The following problem might occur:

- false positives in gesture detection [3]
- higher processing power means higher power demand which gives need for bigger batteries which can result in space problems which influences the possible methods of sensor data processing

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# Cloud Wearables

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## Abstract

Cloud computing is one of the new buzzwords that emerged in the recent years. In this position paper, the use of cloud computing for wearable computing is analyzed and a number of challenges and benefits are illustrated.

## 1. Introduction

In the recent years, the term “Cloud Computing” has been omnipresent and various commercial offerings have added the “Cloud” buzzword to attract attention. For this paper, Cloud computing is used to describe a commercial services that operates datacenter resources and offers utilization-based pricing. This form of cloud computing offers the benefits of the economy of scale to the cloud computing provider while reducing the infrastructure investments and operating costs for the cloud computing customer.

As smartphones are the most important mobile consumers of cloud computing, their similarities and differences are explained in Section 2. In Section 3, a more detailed description of cloud computing will be given. Section 4 lists some challenges and indicates some benefits.

## 2. Comparing Wearables to Smartphones

Power and heat dissipation are challenging to both wearable computers [1] and smartphones. Looking at smartphones today, we can see that although there was considerable progress in power efficiency and battery capacity over the last ten years, the common user experience for a smartphone today is that its battery lasts about one working day. Already this performance is achieved through rigorous power saving when the device is not actively used, not only turning off the screen but also putting the CPU, GPU and sensors into a power-saving mode. To maintain limited functionality even during standby, the device is woken once in a while and performs tasks such as processing

calendar reminders or checking cloud-based services ranging from e-mail to social networks. In order to be context-aware or to instantly respond to user input, a wearable computer is continuously processing sensor data, even when it is not actively used, so both the sensors and the data processing on the CPU will drain the battery even more than on a smartphone. Augmented reality applications will require the continuous use of a GPU to produce 3D graphics which is an even higher burden on the battery capacity and may pose additional heat dissipation problems.

One possibility to lower the power cost of data processing is to partially offload it to a cloud service. What type of processing can be offloaded into the cloud? How can this offloading be implemented effectively, i.e. without losing the benefits of offloading?

## 3. Cloud Computing for Wearables

In cloud computing, a provider offers computing, networking and storage services on demand and with utilization-based pricing. Cloud computing is offered in three flavors called “Software-as-a-service” or SaaS, “Platform-as-a-service” or PaaS and “Infrastructure-as-a-service” or IaaS.

IaaS is comparable to an on-demand operation of a compute center. The cloud computing provider offers basic infrastructure service such as the execution of virtual machines, volume storage and internet connectivity. In PaaS, the operation of the computing platform is performed by the cloud computing provider. The customer packages application software, data and configuration in a container file that is used the cloud computing provider to deploy the customer solution on the cloud computing platform. In SaaS, the cloud computing provider offers access to a multi-tenancy application software package in the cloud. Many existing internet services can be considered SaaS-offerings.

A simple approach to combine wearable with cloud computing is to pair each wearable computer with a

single IaaS-based virtual machine in the cloud. This approach is well suited for prototyping, but it's often not necessary to provision one full individual machine for each wearable computer.

Another approach is to re-use existing SaaS services for wearable computing. A challenge arises from the fact that existing services are often not implemented for non-standard user interfaces, i.e., they expect a web browser or a mobile phone app as client. However, there are a number of SaaS services that expose callable APIs. The main use case for these APIs is building other web-based services, so the API provided may not be optimal for a wearable use case and additional computing may be required to convert data into a form suitable for wearable computing.

To implement a commercial offering of wearable computing on a cloud service, one can implement a custom SaaS solution based on a IaaS or PaaS cloud in combination with other SaaS services. Some cloud providers integrate other SaaS offerings as part of their cloud, one example is the Azure Marketplace [2].

#### **4. Challenges and Benefits for Cloud Wearables**

Transmitting and receiving data is not free energy-wise and looking at commercial offerings, the cost of data transmission isn't zero either. If a wearable computer would be implemented as a simple terminal to a cloud service, i.e. if all input data would be sent to the cloud service that would in turn generate output and send it back to the wearable computer, it is unlikely that this device would be more energy-efficient than a wearable computer that processes everything locally. A simple way to estimate energy efficiency for this type of use is to look at continuous operation times of a smartphone in a video call. One approach to extend this operation time is to have sufficient local processing capacity to initiate such a connection based on context information. Another one is to perform data-intensive and computationally simple preprocessing locally, lowering the amount of uplink data.

If it is assumed that cloud computing is essential for the operation of the wearable computer, we need to deal with the loss of connectivity to the cloud. If all computation is offloaded to the cloud, the wearable computer becomes useless when cloud connectivity is lost. In order to prevent this, a limited computing functionality should remain on the wearable computer. One alternative is to have the full functionality dormant on the device and only activate it when cloud connectivity is lost, then depleting the battery and effectively trading runtime against connectivity while

provisioning the computational capacity of the device for full unconnected operation. An alternative is to provide only partial functionality and accept a graceful degradation while not being connected.

One important aspect of the user experience of a wearable computer is the perceived latency between user interactions and their response. In applications such as augmented reality, increased latency may even lead to simulator sickness effects. On the other hand, many web-based online services have latencies of several seconds but are still perceived as offering low latency interactive experiences by implementing user interface processing in the web browser of the user. It is therefore advisable to perform operations with perceivable latency locally. This is a challenge for augmented reality. However, there are commercial gaming services that control latency effectively in multi-player online games.

In addition to the investment, operation and scaling benefits of cloud computing, a number of properties of a cloud-based solution may especially benefit cloud wearables.

In commercial applications, wearable computers can easily be damaged or lost. If the local state of a wearable computer is replicated in cloud computing, it can easily be replaced. This is especially important for wearable-specific data such as user-specific learned data for context detection as it is very expensive to re-acquire such data.

A cloud-based solution offers an easy way to customize a wearable solution to specific customer needs. A multi-purpose wearable computer can download these customizations from a cloud service, offering individualized wearable user experiences without changing the on-board software.

Starting with a cloud-based approach enables the use of many existing services on a wearable computer without being limited by network bandwidth or computational power. The cloud service can act as a proxy, preparing service data for wearable consumption.

Given that cloud computing services are already available and will gain more functionality over time to support smartphones and other connected devices, the commercial application of wearable computing can benefit from using cloud computing.

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# Evaluation of Augmented Reality Navigation Support for Maintenance Personnel

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## Abstract

*In case of machine failures on-site maintenance personnel can rely on Augmented Reality (AR) maintenance instructions produced by a remote expert. When the instructions are viewed on a hand-held tablet computer or a head-worn display the field of view is limited so that only a restricted area of the maintenance object can be viewed. In these cases navigation instructions might be beneficial to quickly locate an instruction in a new area of work. We have implemented a simple navigation mechanism in our AR maintenance system. It was evaluated by 18 experienced automobile mechanics. The results show that with the navigation help participants completed significantly more positions than without.*

## 1. Introduction

Mobile or wearable computers allow the in situ viewing of stepwise maintenance instructions. By utilizing Augmented Reality (AR) additional visual information about an assembly or a maintenance procedure can be integrated into the real scene [2]. Animated AR instructions are very intuitive and easy to understand. However, we believe that additional visual help can even further improve the effectiveness of an AR maintenance system.

## 2. System

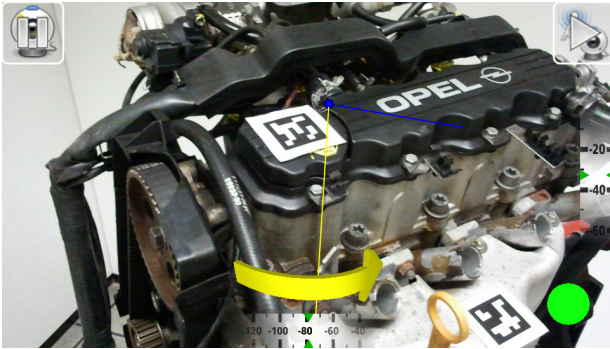
The AR system evaluated is part of our telecooperative maintenance system which consists of an interconnected

AR-VR system. The mechanic using an AR system is supported by an expert using a stereoscopic Virtual Reality (VR) system because unexpected problems often require remote support [1]. This collaborative work of mechanic and expert supported through telecommunication equipment is called tele-maintenance [5].

On the AR system animated work instructions are shown consistently integrated with the real world view. The remote expert creates and sends these animated instructions from his VR system, e.g. when guiding the mechanic in a complex maintenance procedure [4]. In addition to the work instructions the expert also transmits an ideal viewing position from which the mechanic can reach the referenced part and complete the task given. The viewing position and orientation are displayed by an oriented camera frustum.

When either of the augmented content can be seen from the current work position the mechanic can quickly reposition himself and the AR system. Yet, when the instructions are located in a different work area finding the augmented content requires the mechanic to look around. This is inefficient, especially since our AR system requires that the maintenance object is in the field of view in order for the 3D tracking to work. We therefore implemented a navigation help which guides the mechanic to the new work position (see Fig. 1).

The navigation help shows directional arrows indicating the turn or move direction. Additionally, two scales show the horizontal and vertical angle to the target. The horizontal angle to the target position is also visualized by two lines from the target point to the target position and the current position.



**Figure 1. The navigation help used in the evaluation.**

### 3. Evaluation

#### 3.1. Hypotheses and Independent Variables

The AR system without navigation was evaluated earlier in a telecooperative maintenance task [3]. However, since we believe that using additional visual instructions is beneficial to the mechanic for quickly repositioning and reorienting we integrated this functionality. For the evaluation we hypothesize:

$H_1$  Locating a part of a complex maintenance object, positioning and orientating the camera will be faster when using the navigation help ( $D_{Nav}$ ) than without it ( $D_{\overline{Nav}}$ ).

If we do not find evidence supporting the hypothesis there are two possible explanations: either the navigation instructions are not helpful to the task or the instructions are distracting and are therefore ignored by the user.

The only independent variable in the evaluation is the presence or absence of the navigation instruction ( $D_{Nav}$ ,  $D_{\overline{Nav}}$ ).

#### 3.2. Apparatus

We used a video AR system consisting of a mobile phone with a back-facing camera and a 4.3 inch screen. The tracking was done using multiple 2D markers. The target was visualized as a colored 3D surface mesh. The camera target position was shown as a camera frustum. The navigation instructions were shown as in Fig. 1.

#### 3.3. Procedure

In the experiment the participants had to locate parts of an automobile engine by using the AR system. The parts

to be found in the experiment are all required to be removed during the exchange of the camshaft housing. Overall 24 positions were included in the experiment. When the AR system was positioned at the target, it had to be held steady for two seconds — we used a 10% movement margin. When participants did not finish within 60 seconds the experiment continued with the next position.

To limit the influence of the individual variances we used a within subject experimental design. The participants therefore used both systems  $D_{Nav}$  and  $D_{\overline{Nav}}$ . The system used was alternated every three positions. The first six positions were used for training the use of the system.

#### 3.4. Participants

28 participants took part in the evaluation. They consisted of three groups ( $G$ ). One group were young automobile mechanics ( $G_1$ , age = 22 years,  $SD_{age} = 3.3$  years), one group were experienced automobile mechanics ( $G_2$ , age = 29 years,  $SD_{age} = 1.1$  years) from the German army and one group were employees from Fraunhofer FKIE ( $G_3$ , age = 31 years,  $SD_{age} = 5.5$  years). All participants had a binocular vision at reading distance of at least 0.7 dpt. The automobile mechanics were compensated monetarily for the participation.

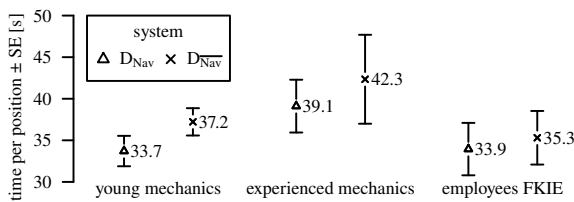
#### 3.5. Control of Extraneous Variables

The positions and parts to be located were selected to be fairly similar in difficulty. Yet, to compensate for the case that one set of positions or sequence of positions is easier than the other one we divided the participants in two groups. One group ( $A_1$ ) started the experiment using  $D_{Nav}$ , the other group ( $A_2$ ) first used  $D_{\overline{Nav}}$ .

#### 3.6. Results

On average participants finished 81.5% ( $SD = 14.8\%$ ) of the positions with navigation help ( $D_{Nav}$ ) and 71.9% ( $SD = 22.9\%$ ) without navigation help ( $D_{\overline{Nav}}$ ). A similar advantage was found for the time required. Using  $D_{Nav}$  it took on average 34.9 s ( $SD = 8.0$  s) and using  $D_{\overline{Nav}}$  it took 37.6 s ( $SD = 9.3$  s). The difference of the results per participant and display type is on average 9.6% for the percentage of completed positions and  $-2.7$  s ( $SD = 6.9$  s) regarding the needed time. The advantage of  $D_{Nav}$  can also be seen in Fig. 2 and Fig. 3.

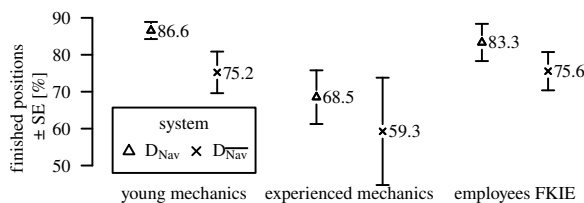
An analysis of the number of completed positions for normality grouped by  $D$ ,  $A$  and  $G$  shows significant ( $p < 0.01$ ) deviation from normality for some of the subgroups in a Shapiro-Wilk test but no significant deviation in a Kolmogorov-Smirnov test. We therefore assume normality. The analyses of the time needed show no significant



**Figure 2. Time needed per position.**

( $p > 0.05$ ) deviation from normality in either tests. A Levene test for homogeneity of variances shows no significance for the number of completed positions ( $F_{11,44} = 1.27$ ;  $p = 0.28$ ) and for the time needed ( $F_{11,44} = 0.71$ ;  $p > 0.72$ ). An ANOVA for the number of completed positions with  $D$  as a within,  $A$  and  $G$  as a between subject factor shows a significant effect for  $D$  ( $F_{1,22} = 5.88$ ;  $p = 0.02$ ). No significant effect was found for the time. A post-hoc comparison using a one-sided t-Test regarding a greater number of finished positions when using  $D_{Nav}$  shows strong significance ( $t(27) = 2.52$ ;  $p = 0.009$ ).

The observed effect of  $D$  is also noticeable in Fig. 2 and Fig. 3. The time needed is smaller and the percentage of completed positions is greater when using  $D_{Nav}$  than when using  $D_{Nav}$ . What is also apparent in the diagrams is that the results of the young mechanics ( $G_1$ ) and the results of the FKIE employees ( $G_3$ ) are very similar.



**Figure 3. Completed positions.**

### 3.7. Discussion

The participants were able to fulfill the given task. The percentage of completed tasks was acceptable — all subjects finished at least 59% of the tasks. The average time needed was also adequate with a maximum at 42 s. The experimental results show a significant difference between the two display modes. Yet, the differences are small.

The results of the three groups differ. However, this difference is not statistically significant. The results of the employees of Fraunhofer FKIE, who had no experience with the used automobile engine, are even comparable to those of the participants with a background in automobile maintenance. However, this does not mean that an untrained person can be instructed as quickly as a trained one to locate

a certain part of the maintenance object. Especially common parts or positions which have a name, e.g. at the first cylinder, can be described more quickly vocally or textually to a trained person. For atypical positions or hard to describe parts there is an advantage in using an AR navigation support system.

The individual feedback from the participants indicated that the localization of the AR system must work reliably. The unsteady tracking, especially just before reaching the destination, was frustrating to the participants. Yet, a major source of the unsteadiness were the participants themselves. Although they were instructed before the experiment and during the training that a marker needs to be visible in the camera image for the tracking to work they still sometimes moved the system so that no marker was visible. The not working tracking was even indicated with a large filled circle (see Fig. 1). Yet, it still took some of the participants considerable time until they noticed this. A possible workaround could be the continuation of the tracking using an inertial system or the display of an even larger notice that the tracking is invalid.

## 4. Conclusion

The experiment showed the applicability of an AR navigation help for localizing parts and positions of a maintenance object. We believe that although AR provides an intuitive display of virtual content it is still beneficial to additionally support the user to become aware of this augmented content.

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# Adaptive Location-Related Context Framework for Wearable Solutions

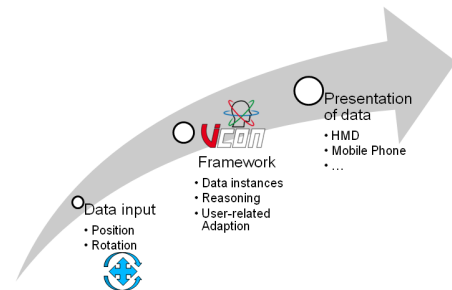
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## Abstract

*This paper presents a concept for an adaptable data system that could be used as a wearable solution in the daily life. Based upon positioning information (GPS, field strength measurements, PDR, etc.), time etc. reasoning can provide the user, via augmented reality, specific information e.g. of the environment regarding the position. Additionally the user can change and extend information in the context framework to build her or his own augmented reality.*



## 1. Introduction

The scenario is to assist a pedestrian via augmented reality in her or his daily life. A wearable system that is capable of doing this task has to be aware of its users preferences, activities, locations, etc. The related challenge is that the system has to be able to solve problem, what information the user needs in the current situation and scenario. The user should be able to interact with the system and customize the assistance that will be provided.

Using inclusive design approaches for the early conceptualization of products, such as in [3] and [4] for data configuration, the user is able to proactively modify, adapt, or add new data in the underlying model (e.g. information about the environment, personal information) by leveraging the data into an forward-chain logic based ontology. This data can be presented on different user interfaces (like e.g. HMD) to gain local context information.

Figure 1 illustrates the approach pursued in the concept. Sensorial data (see section 2) is used as the input for the VI-CON framework to present information on user interfaces. The framework itself can be easily used to change all requested information.

Using this approach, every information which can be stored in an ontology, can also be the output of the system.

**Figure 1. Creating environment context output**

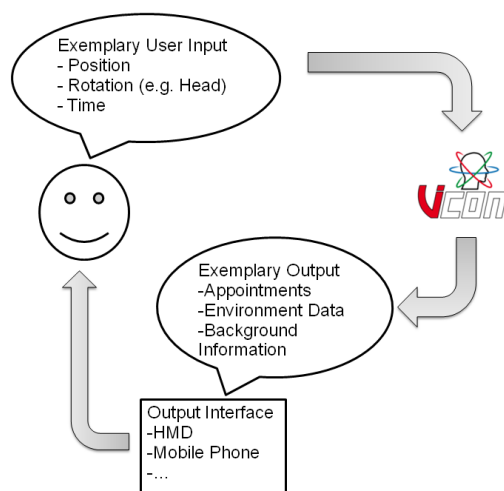
## 2. Localization

Pedestrian Localization provides a useful application for the user. Scenarios for such applications are e.g. tourism, rescue teams, military, navigation. Various solutions for localization of pedestrians are available, they can be separated in two groups: indoor and outdoor. The accuracy required for the localization will also determine the methodology that has to be implemented. Preferred methods for outdoor localization are for example GNSS, field strength measurements (WLAN, GSM, Bluetooth), PDR, etc.[1]. Preferred methods for indoor localization are the use of pre-installed indoor communication infrastructures, laser, radar, sonar, camera, motion sensors, etc.[1].

The scenario for the proposed wearable solution is that the pedestrian is moving through indoor and outdoor environments. In this scenario relevant information of the environment such as building specifications, site seeing, transport, weather, etc. could be transmitted to the user.

In this case the localization doesn't require high precision, available technologies should be used both in hardware and software. Available hardware are smart phones, wearable computers with embodied sensors, head mounted displays, etc.

With respect to the example scenario the pedestrian will be walking with a head mounted display and a wearable computer. The wearable computer is equipped with motion sensors (Accelerometer, gyroscopes, magnetometer, GPS and GSM). A sufficiently precise localization for this indoor/outdoor scenario can be achieved by combining the use of motion sensors, GPS and indoor communication infrastructure, like shown in [2] and [5]. With available maps of the environment the localization can be even more sophisticated. To be sure where the pedestrian is looking at, an IMU (Inertial Measurement Unit) will be on to the head mounted display, so the head movements can be traced.



**Figure 2. Scenario example including user input and output of the system**

### 3. User Adaption

One important aspect of the VICON framework was to create an easy learnable administrative interface to maintain the complete ontology and extraction step (see [6]). A graphical user interface was created to add the functionality of the user to add, delete and change data instances. Related to the connection of the local positioning and rotation, the user is able to define situations which result in different data output.

Details about surroundings of a specific location can be defined in the VICON framework including different aspects and attributes. One attribute of one ontology instance should be the definition of a position, where the information should be presented.

One main problem of the usability of all related data is, which information is useful for the user. The system is capable of defining a persona (see User Model ontology class in the next section) which includes all personal interests and can be used in the frameworks reasoning step to reduce presented information. The current position of a user in an environment is used as an input for the system, so user specific information about the surrounding can be illustrated.

### 4. Information Distribution

Figure 2 presents an exemplary configuration. In addition to the feature to select and present already existing information, the user is able to add custom information into the framework. Appointments with respect to their location can also be inserted.

The ontology is divided into the following classes:

- **User Model**  
Analogue to the original VICON ontology, an user model class is needed for the purpose to define user needs and interest as an instance of the user model class. In the first version the current user of the system can be identified by user-name and password, later without user input by face recognition, retina scanners etc.
- **Beacon**  
Instances of the beacon class define spacial places. Each object correspond an place of interest including coordinates (+ optional rotation) and an ID. Dividing this information from the output instances creates the advantage to create location beacons which makes it simple to connect to output instances.
- **Appointments**  
This class defines all direct created and used appointment instances. Each instance can also be connected to beacon instances by an analogue connection of beacon ids as for environment output instances.
- **Environment Output**  
Corresponds to all presentable location-related output instances. Each instance contain either an attribute of one or more beacon ids.

With respect to the feature, that the user can change, add and delete all instances in these classes, the system is highly adaptable to user needs and is also as simple as possible.

The reasoning part consists of rules, which are directly related to the current situation and use the connection attributes (beacon ids and appointment time) to add all relevant instances to a new created class. Analogue to the recommendation class of the VICON project (see [6]) new classes are created throughout the reasoning process, but in this case the result is just one new class containing all currently visible outputs as members.

## 5. Conclusion

In this paper we presented a concept how to support people in their daily life. As a representative example for daily life activities, a scenario was chosen with versatile situations. Within the concept, ontologies are used as a means for storing relevant information. This information can be presented in a context sensitive way based upon different data input. The applied framework is characterized by containing different types of information, which are useful for the accomplishment of daily life activities. Compared to other existing solutions for similar purposes, the main advantage proposed in this concept is the personalization of the output data by the user so she or he can personalize and reduce the output to the persons interests.

## 6. Future Work

By applying this concept to wearable computing settings, different scenarios are possible. For instance, van der Heijden et al. [7] presented a system which would be able to learn from scenarios and also could react to these situations itself. One main problem with reacting systems is, that usually the configuration is very complex. Regarding future work, the presented system needs further development in machine learning algorithms and also the feature, to manipulate these by the user.

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# Novel Tracking Techniques for Augmented Reality at Outdoor Heritage Sites

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## Abstract

*Augmented Reality (AR) technology can provide a novel and interesting approach for presenting cultural heritage content to the general public. Recent advances in AR research and the quick uptake of powerful mobile devices now means AR systems are a viable option for heritage institutions, but there are still many challenges that must be overcome before high-quality AR experiences are commonplace. AR systems for outdoor sites can be particularly problematic due to difficulties faced when designing robust tracking systems. This paper outlines four novel tracking techniques for AR at outdoor heritage sites.*

## 1. Introduction

Cultural heritage sites and museums are tasked with providing information about the past to members of the public in a clear and easily digestible manner, and in a way that does not require large amounts of the visitors' time. However, there are challenges to overcome to achieve this - walls of text overwhelm visitors, complex and specialist language is used where the readers have only a passing interest, and uninteresting pictures fail to engage. For this reason, the heritage sector often seeks new ways to engage visitors with their sites, and are often keen to harness technology to achieve this. Previous methods have included static computer kiosks to provide information to visitors [1], audio tour guides [2], mobile device-based tour guides [3, 4, 5], and even robot tour guides [6, 7].

Augmented Reality (AR) also offers a novel and interactive way of presenting information to visitors. An AR system is a system which enriches ("augments") the real world with computerised information and objects (an example of this is shown in Figure 1). Milgram et al. [8] defined the Reality-Virtuality continuum, which provides a taxonomy for all Virtual Reality (VR) based systems and encompasses everything from *reality* (the real world) to complete



**Figure 1. A mobile Augmented Reality application showing a ruined building superimposed with a virtual intact version.**



**Figure 2. The reality-virtuality continuum (adapted from Milgram et al. [8]).**

*virtuality* (a completely immersive, entirely virtual world). According to their classification, AR is a type of *Mixed Reality*, which describes any combination of reality and virtuality (see Figure 2). It should also be noted that their definition is not tied to a particular type of hardware, notably Head-Mounted Displays (HMDs), which have been a popular choice for AR systems.

Azuma [9] also notes that AR is not tied only to HMDs. Azuma builds upon the definition, and observes that in addition to being a blend of the real and virtual, AR should be interactive in real time and registered in 3D. Azuma con-

siders that, although AR is most commonly associated with augmenting the users' sense of sight, it can also cover the other senses such as hearing [10, 11].

## 2 AR for outdoor heritage sites

Developing AR systems for outdoor applications is arguably more difficult than it is for indoor applications [12]. The environment and resources, such as lighting conditions and electrical power, cannot be as tightly controlled, and hardware cannot usually be left outdoors. This typically means that mobile computer systems must be used, which can be uncomfortably heavy to wear and expensive if it is a wearable system combined with an HMD. The lack of ideal conditions often means that marker-based tracking systems cannot be used, which leads to a reliance on other methods such as those based on Global Positioning System (GPS) and inertial sensors, which can be inaccurate. Nevertheless, numerous systems for outdoor sites have been successfully developed and implemented.

The ARCHEOGUIDE project [13] used an HMD and wearable computer combination to guide the user through an Ancient Greek outdoor temple site. The system also used a tablet computer to display location-sensitive information to the user, such as pre-rendered 3D reconstructions and images of archaeological finds, which are streamed to the device via a wireless network. The project was successfully deployed in 2001, using off-the-shelf hardware components. However, during testing it was found that the hardware was uncomfortable to wear for long periods [14].

The Augurscope project [15] took a different approach. There were no wearable components as it combined a wheeled tripod with a computer and camera system, allowing users to wheel the device around a castle site in Nottingham, England. However, despite its mobility, it was found that users were reluctant to move the device (perhaps due to the size and weight of the device and uneven ground surface), and that groups of people of different heights meant constant adjustment of the device was necessary.

Another outdoor system using mobile technology is MARCH [16]. Unlike ARCHEOGUIDE, the then contemporary (year 2009) consumer mobile phones had the power and features to implement an AR system. The MARCH system was developed for the Gargas prehistoric cave site in France, and uses AR to superimpose enhanced images of cave painting over the remains, which can be difficult to interpret. As the system uses a mobile phone, it is completely mobile and does not suffer from the comfort problems encountered by ARCHEOGUIDE.

The Mobile Augmented Reality Tour (MART) system [17] also demonstrates a mobile outdoor augmented reality system. The researchers used popular tourist spots in Gyeongbokgung, Korea to test the system's tracking tech-

nology. Using their system, 3D characters are correctly superimposed in numerous environments. However, even though the technology is targeted at mobile phones, the results presented were obtained from a laptop prototype.

The main issues faced in designing AR systems for outdoor sites are those of tracking effectively without the use of markers in an environment that may be devoid of features to use for tracking, and also ensuring any apparatus used is weather-proof and vandal-proof. Also, as with indoor sites, hardware used must be powerful enough to support AR applications. There is also the issue of making software available to visitors - if the user has to download and install software then there needs to be infrastructure in place to allow this.

For an AR system to be viable for a heritage institution, it cannot feature expensive ad-hoc hardware solutions. For this reason, the possible solutions presented here were designed with consumer-level tablet computers in mind. They also attempt to use existing marker-based tracking technology, for example ARToolkit<sup>1</sup>, in order to reduce development time which would be greatly extended if a custom tracking system were to be developed. By using markers in new ways, it is hoped that the problems that prevent traditional marker-based tracking being used outdoors can be overcome. In the following section we present four techniques to facilitate AR at outdoor heritage sites. Although these techniques were designed with outdoor heritage sites in mind, they could also be applicable to other domains where position tracking is beneficial, for example aiding workers in the assembly of products in manufacturing plants, or being used as part of a tour guide system for tourists in an unfamiliar city.

## 3 Four marker-based techniques

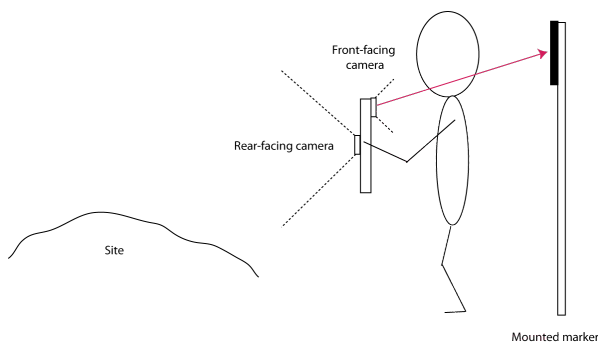
### 3.1 "Over-the-shoulder" fiducial markers

This technique requires a device that features both front- and refacing cameras, such as the Apple iPad 2 or Samsung Galaxy Tab 10.1. Fiducial markers are placed on objects around the site, and situated such that the front-facing camera can read them over the user's shoulder (this may involve the user having to hold the device in an off-centre fashion). The marker is tracked by the front-facing camera and virtual content augments the view from the rear-facing camera. This is illustrated in Figure 3.

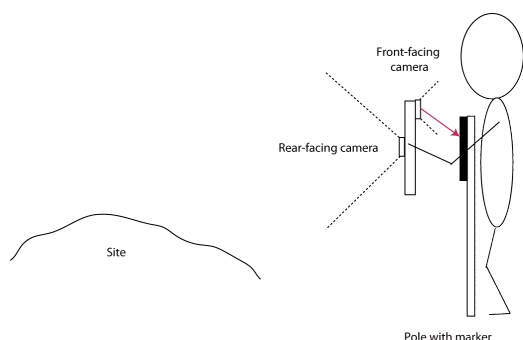
### 3.2 "Marker hugging" technique

This technique also requires a dual-camera device. A fiducial marker is placed on a pole or mount, facing in

<sup>1</sup><http://www.hitl.washington.edu/artoolkit/> [last access 27/03/2012]



**Figure 3. "Over-the-shoulder" markers**



**Figure 4. "Marker hugging" technique**

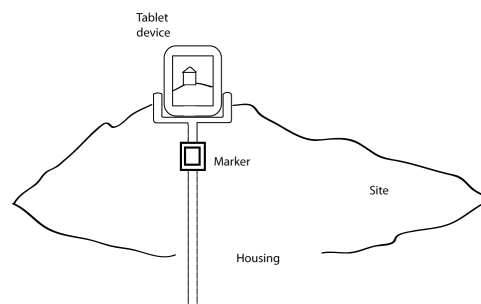
the same direction as the user's view (towards the site). The user then places this marker between themselves and the mobile device, so the front-facing camera can read the marker. The front-facing camera then tracks the marker, which is used to augment virtual objects correctly over the input from the rear-facing camera. This is illustrated in Figure 4.

### 3.3 "Flagstick" device housing

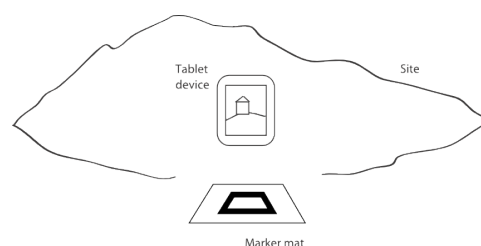
A housing designed to hold the tablet device is placed at an unchanging location which is pre-calibrated (via GPS or direct measurement). By using a fiducial marker on the housing, the system pre-registers and calibrates the location of the device. Another option is for the user to carry a single housing with them which is placed in holes around site, much like a flagstick in golf. Inbuilt inertial sensors can allow the position to be tracked if the housing allows for rotation. This is illustrated in Figure 5.

### 3.4 "Doormat" markers

A calibration mat featuring a marker is placed by direct measurement. The user stands at the mat so the device can read the marker to allow the system to register the initial



**Figure 5. "Flagstick" housing with mounted marker**



**Figure 6. "Doormat" markers**

location. Further tracking is achieved in real-time using the device's internal sensors. This is illustrated in Figure 6.

## 4. Discussion

All of the solutions in Section 3 require the device to stay still or to stay within a small area to maintain tracking stability. This can detract from the experience and takes away from one of the main attractions of AR, which is that virtual objects are registered in a 3D environment. When presented with an in-situ 3D representation of a site, users may expect to be able to freely explore whilst retaining tracking. A possible solution to this is to utilise the device's internal sensors after the marker leaves the camera's view or when the device leaves the pre-calibrated housing, but this will depend on the stability of the sensors.

There is also the issue of site modification. Each technique requires additional materials or structures to be placed around a site, which may be undesired or even forbidden by law. Even if modification of the site is allowed, anything added to the site should be weather- and vandal-proof, as many sites are not staffed. However, it may be possible to facilitate tracking using existing site features, such as by integrating markers into pre-existing information panels, or by using natural feature tracking (NFT) on suitable features.

The awareness of AR among the general public has increased greatly in recent years. Smart phone users are familiar with scanning Quick Response (QR) codes placed in

various media, and the increase in AR applications available now means that the public are aware of the multiple functions of such markers. Thus, many people will associate seeing such fiducial markers with the presence of AR technology, which will lead to greater usage. It also helps that markers are cheap and easy to produce and replace, and that existing AR development tools, e.g. ARToolkit, provide stable and robust marker tracking over a number of platforms, including iOS and Android for mobile devices.

Cultural heritage institutions often seek to attract families to their sites. With the solutions in Sections 3.1 and 3.2, it is not easy for groups of users to share the experience as it relies on users to stand in a specific location. There are also accessibility issues - for example, the placement of markers may only be suited to users within a certain height range.

We are currently evaluating the feasibility of the four techniques presented here across implementation concerns such as inertial sensor stability, dual-camera processing and initial and continuous tracking calibration.

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# Mobile AR in the outdoors: watch the clouds

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## Abstract

*Even the most modern wearable devices do not provide sufficient resources for the complexity of outdoor AR algorithms, induced by the uncontrolled environment. In this paper, we present a framework whereby nearby infrastructure, called cloudlets, is leveraged with an execution environment to provide additional computational power and storage capacity. The execution environment is dynamically composed with service components and data, dependent on the actual user context. We discuss the architecture and provide first experimental results on a distributed mobile AR application that has been adapted to the cloudlet paradigm.*

## 1. Introduction

Offering a plethora of rich sensing capabilities in an easily wearable device, smartphones are a highly attractive platform for mobile augmented reality applications. With quad-core processors and gigabytes of memory, modern smartphones are computationally capable to perform real-time detection and tracking of objects in AR applications. Limitations in size, weight and heat dissipation make mobile devices intrinsically resource poor, compared with desktop or server infrastructure [8]. For example, using the GPU on a smartphone rapidly drains the battery and prohibitively reduces the autonomy - and thus mobility - of its users. As a result, mobile AR developers need to take measurements that hamper the user experience, e.g. by sacrificing the accuracy and quality of state-of-the-art algorithms to meet latency requirements [3], or by introducing an offline preprocessing stage on a remote server [1].

In outdoor environments, the computational and data requirements of mobile AR applications are even more challenging. Compared with indoor environments, variable and difficult lighting conditions require particular detection algorithms, objects are typical of larger scale, e.g. 3D construction information of buildings [2], and the larger area explored by users contains a multiple of the number of objects to be recognized. Besides computational and stor-

age constraints, outdoor mobile AR is typically based on time-varying user context environment, as demonstrated by Google's Project Glass [6] whereby the application continuously reacts to new events in the user's vicinity.

To overcome smartphone resource limitations and to cope with the larger scale of complexity in outdoor environments, mobile AR applications need to be supported by the cloud. Already in the early days of mobile AR development, researchers acknowledged the need to offload computationally intensive parts to a nearby server that was typically accessed through a local wireless access point. With the advent of cloud computing and broadband 3G/4G wireless connections, also in outdoor environments external resources are within reach. Furthermore, leveraging AR applications with cloud-based components allows to analyze in real-time the current context and provide the required updates upon unanticipated events to the mobile device. Engaging the cloud introduces however a number of challenges. The latency between mobile device and cloud may be prohibitive for applications with strict real-time constraints. Also, a lot of information is only relevant for a limited period in time or for a small number of users, e.g. dependent on the geographical distance.

In this paper, we outline our vision on how the cloud can support mobile AR. We are working on a management framework that deploys for each user an execution environment on nearby infrastructure, called cloudlets. The execution environment is dynamically composed with application components and data, based on context parameters such as geographical location, time or available wireless bandwidth. Time-critical application components and personal data are optimally distributed over the mobile device and the execution environment on the cloud, while background tasks and large object database are centrally managed in the cloud. The proposed framework is an extension of the cloudlet concept coined by Satyanarayanan et al. [8]. The authors use the virtual machine as unit of deployment and use a thin client approach. In contrast, we exploit the increased computational capabilities of smartphones to run the most time-critical application components on the device. Furthermore, offloading at component level offers

more flexibility to cope with the dynamic context parameters and heterogeneous devices in mobile environments.

The remainder of this paper is structured as follows. In section 2, we describe the architecture of our framework and the component-based approach. In section 3 we present our current implementation. In section 4, we present experimental results on the performance of a distributed mobile AR application, clearly demonstrating the benefits of the cloudlet approach. In section 5, we repeat the most relevant conclusions and outline future work.

## 2. Proximate cloud model

Figure 1 illustrates our vision in which nearby resources are leveraged with an execution environment to provide the required computational and storage for latency-critical tasks. Instead of running the complete application on the mobile device, application components can be offloaded to the cloudlet or the cloud. Different cloudlet configurations are supported. Some cloudlets are formed by already installed devices with network connectivity that have underutilized resources. In a home network, many devices are left always on, e.g. for home network media file sharing, but rarely require all available resources. Given the widespread deployment of Wi-Fi in residential areas, there are few places where a mobile device is out of reach of any of these underutilized devices. Collections of mobile devices may form an ad-hoc cloudlet, e.g. in a train carriage where a lot of mobile devices remain in the same configuration for a relatively long period. Of course, sharing resources of personal devices introduces challenges of trust and energy consumption. We believe these challenges can be overcome with virtualization techniques becoming available on mobile devices [7], and the establishment of an incentive-based mechanism following the tit-for-tat principle as is found in P2P networks [9]. Other cloudlets may be composed with dedicated infrastructure, e.g. current public Wi-Fi hotspots could be enhanced with a server providing resources, or mobile operators may integrate infrastructure in their mobile aggregation network.

As the user moves, the execution environment on the cloudlet may contain different application components and data. Operating at the component level, this architectural framework provides the required flexibility for outdoor mobile AR applications with continuous context changes. When the user moves, the execution environment can be dynamically reconfigured. This allows for example to load the execution environment with location-specific service components and data, e.g. an augmented reality tourist guide. Moreover, information and services can be shared between multiple users at the same location. For example, in tracking applications, users could reuse the map that has been previously constructed by others at the same location.

## 3. Implementation

We implemented a prototype of our framework in Java, which allows it to run on a wide range of platforms, including Android, the popular mobile operating system. We built the execution environment with OSGi, a service oriented module management system that allows to dynamically register software modules. OSGi offers life cycle component management, automatic resolution of dependencies and, using R-OSGi, the distribution of components across different OSGi instances.

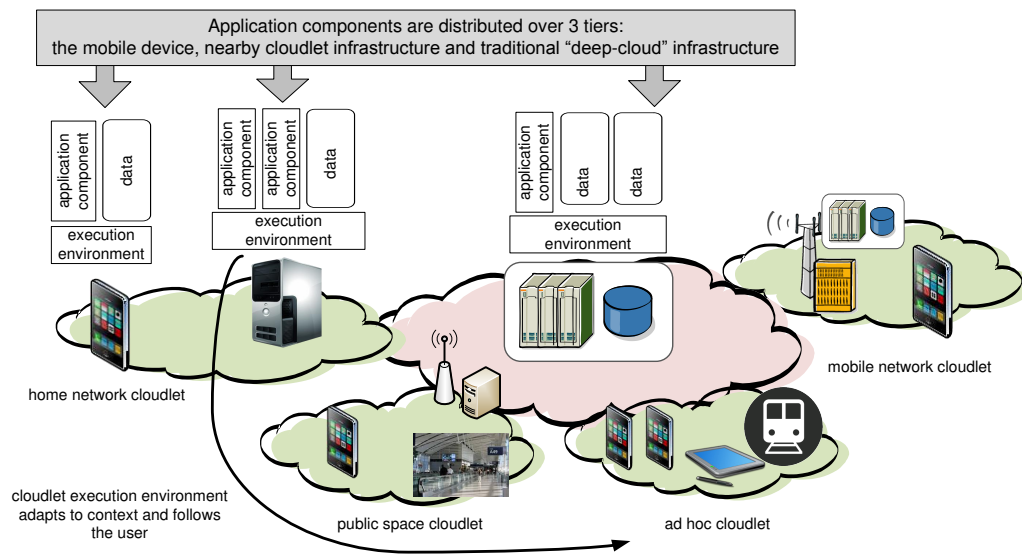
Each application component is registered as an OSGi bundle to the execution environment. For each bundle, the providing interfaces are proxied by the Execution Environment (EE). Components receive a reference to the proxy, which allows the EE to transparently monitor all calls to the proxied object, and to choose whether to forward incoming method calls to the local object or to a remote duplicate. Consequently, all application components can be transparently distributed between the cloudlet and the mobile device.

For each component, the application developer must provide an XML description specifying performance constraints, such as maximum processing time per frame, and the range of configurable parameters, e.g. the number of feature points to analyze. At runtime, the performance of the application may vary because of many factors, e.g. wireless bandwidth fluctuations, more complex scenes to analyze, or periodic background tasks on the mobile device. The framework will react by reconfiguring parameters or by recalculating the optimal deployment of components between EEs deployed on the mobile device and the cloudlet. In the current implementation only predefined actions are configured. More details on decision algorithms for distributing components with multiple configuration options can be found in our previous work [10].

## 4. Use case: distributed PTAM

To illustrate the merits of our 3-tier approach, we have combined an existing augmented reality application using markerless tracking (based on the Parallel Tracking And Mapping (PTAM) algorithm [5]), with an object recognition algorithm [4]. PTAM is a widely used tracking algorithm in a priori unknown environments and is hence a good candidate to be incorporated in outdoor mobile AR applications. A screenshot of the application is shown in Figure 2. The application continuously analyzes frames captured by the camera of the mobile device to estimate its current pose. Recognized objects are indicated with a white border and a 3D object is rendered as an overlay.

The application comprises the following components:



**Figure 1.** Application components and data are distributed over the mobile device, the cloudlet and the cloud. This allows to differentiate between latency critical components and background tasks.



**Figure 2.** The application tracks feature points (right) to enable the overlay of 3D objects (left).

- **VideoSource** fetches video frames from the camera hardware. These frames are forwarded to the Tracker for analysis, and rendered with an augmented reality overlay by the Renderer.
- **Renderer** outputs the captured frames and the generated 3D overlay to the camera display. The 3D objects are aligned according to the camera pose that is estimated by the Tracker.
- **Tracker** calculates the camera pose by matching a set of 2D image features to a known map of 3D feature points, maintained by the Mapper.
- **Mapper** At regular intervals, the Tracker sends frames to the Mapper for map generation and refinement. By

matching 2D features in a set of keyframes, the Mapper estimate their 3D location in the scene and generates a map of 3D feature points.

- **Relocalizer** tries to relocate the camera position when no feature points are found in the captured frames until the tracking can be resumed
- **Object Recognizer** tries to locate known objects in the keyframes of the Mapper. The 3D location of recognized objects is notified to the Renderer that produces an appropriate white boundary around the recognized object.

Our current implementation exists of a smartphone and a laptop taking the role of cloudlet server. The laptop is equipped with an Intel Core 2 Duo 2.26 GHz running Linux. The smartphone is an Android LG Optimus 2x with a dual core Nvidia Tegra 2 CPU of 1 GHz. The different components have been implemented as OSGi bundles. To speedup the computation, an important part of the image processing is implemented in native C/C++ code that was wrapped in OSGi components by means of the Java Native Interface. Native libraries have been compiled for both the x86 and ARM processor architectures. The appropriate library depends on the underlying platform and is loaded at runtime by the OSGi framework.

We evaluated 3 deployment configurations of the AR components. In configuration A, all components are running on the mobile device. In the configuration B, the components not having real-time constraints, i.e. the Mapper



**Table 1. Execution time in ms in 3 deployment scenarios. The resolution of the captured frames is 800x480.**

configuration	A	B	C
<b>Tracker</b>	64	34	378
<b>Relocalizer</b>	21	21	2
<b>Map init</b>	2 804	1 124	176
<b>Mapper</b>	2 470	519	396
<b>Object Recognizer</b>	18 682	1 495	2 281

and the ObjectRecognizer, are outsourced to the laptop. In configuration C, also the Tracker and Relocalizer are offloaded to the laptop, leaving only the components that access device specific hardware on the device.

Table 1 presents the execution time of the individual components for each configuration. The results represent the duration of a single operation of the component: tracking one frame (Tracker), relocalizing one frame (Relocalizer), initializing the 3D map (Map Init), refining the map with one keyframe (Mapper) and for object detection in one frame (Object Recognizer).

The duration to track a single frame is the most important factor affecting the user experience, since this has to be performed for each camera frame that is fetched. Only in deployment configuration B, an acceptable framerate of 30 fps is realized. Compared with scenario A, outsourcing the Mapper and ObjectRecognizer to the laptop allows to allocate more resources to the Tracker. On the other hand, outsourcing the Tracker component to the laptop drastically increases the execution time of the Tracker since in this case, the captured frames as well as the results must be transferred over the wireless connection. The same observation holds for the Object Recognizer, which receives its frames from the Tracker. In scenario C, both components are colocated, whereas in scenario B these frames have to be transmitted over the wireless network. These results clearly indicate the advantage of our fine-grained component based approach, allowing much more flexibility in deployment configurations. Overall, outsourcing components results in a reduction of the execution time with a factor 2 to 12.

## 5. Conclusion and future work

Despite rapid improvements of mobile device hardware capabilities, the stringent computational and data requirements of mobile outdoor AR applications can only be provided by the cloud. In this paper, we have presented our framework in which users can outsource components to an execution environment on nearby cloudlet infrastructure. The offloaded application components and data may vary depending on the user context. Many research questions are

currently being investigated. A first set of challenges relates to the management of the cloudlet and its composing nodes. As the user moves, his mobile device needs to connect with other cloudlets. One solution is to automatically select the most powerful node in the cloudlet (e.g. the desktop in a home network) as master node managing the cloudlet. Furthermore, we are working on algorithms that determine the optimal balancing of application components between the mobile device, the cloudlet and the cloud, based on runtime parameters as battery capacity, network bandwidth and application load. A last set of research questions is related to the reuse of service components and data between multiple users. Specifically for mobile AR, we are implementing the use case whereby mapping information is shared between multiple users to enable collaborative outdoor AR.

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# Future Challenges to Actuate Wearable Computers

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## Abstract

This workshop paper discusses how actuated materials and substances can provide compelling functionality for future wearable computer systems. We present a number of current opportunities and describe the future challenges of integrating advanced actuators into wearables

## 1. Introduction

Wearable computers are a compelling technology that allow computational tasks to be performed out of sight and near the user. To be useful they employ methods of input and output (sensors and actuators). These sensors include temperature, motion or more complicated GPS inputs. Actuators allow computers to manipulate the real world based on the interpretation of the sensors. For example, arrays of belt worn vibration actuators were combined with a GPS to support navigation tasks [1]. Although this type of functionality is very useful and powerful we believe the use of actuators on wearable computers is only in its infancy and there is a great opportunity to advance them further. We have been pondering on the question “Why are more interesting and capable actuators not around?” The aim of this paper is to discuss the potential uses of advanced actuators and to examine the challenges of building more capable and advanced actuators for wearable computing.

## 2. Opportunity for Actuated Wearables

Wearable computers are increasing in popularity as they can be programmed to respond to a stimulus and react in automatic ways. For example, there are a number of projects utilizing clothing based computing [2, 3] where devices exchange information with other users in close proximity and interact using customized input devices. Consider using a wearable computer with a virtual keyboard to input data; because the

projection does not provide suitable haptic feedback, you have to look at the keyboard to keep your hands on target. This is not a problem with a real keyboard because the feel of the object allows the user to take their eyes off the keyboard by using the bumps on the home keys. Now there are great opportunities for wearable computer systems to leverage and innovate actuation technologies to extend their functionality. For example, if an actuator was embedded into gloves that made the fingers slightly straighten on command, you could simulate the hills and valleys of the keyboard and allow the user to take their eyes from the virtual keyboard. This type of simulated haptic feedback has the potential to increase user performance and the immersive nature of current wearable systems.

## 3. Advancing Sensors and Actuators

Recently, there has been an increased interest in widening the number of sensors that are used in computers. Nintendo’s Wii Remote with its fairly accurate and cheap position sensing (followed by Microsoft Kinect and Sony Move) has shown that there is an interest in adding new sensors to devices. Apple has also contributed to pseudo-wearable computers with addition of gyros, magnetometers and additional sensors in their mobile devices. These have allowed new methods of interaction. Over the last five years more and more sensors are being added to consumer devices based on the success of the first generation mentioned above.

With the flood of new sensors being added to consumer computing devices, one wonders why actuators have not taken off to the same extent? One reason is that sensors are much easier than actuators to design, manufacture and embed. As sensors measure a physical effect they tend to be smaller compact and do not require the same complexity of an actuator used for a physical effect. However, recently there have been a number of advances that show promising results for the actuation methods that change the viscosity of fluids

and potentially fabrics. For example[4], demonstrated that electro-metallic materials could change their viscosity allowing for the creation of a surface that can change its shape[5] to imply the physical shapes on the surface have a physical presence. This allows better affordance to the user than that of a non physical interface such as the virtual light projected keyboard mentioned in section 2 above

## 4 Wearable Actuator Challenges

Bringing these new forms of actuators to wearable computers requires we overcome a number of challenges. There are a number of parameters we believe will influence future actuation devices.

### Power Usage

With current battery technologies, mobile devices carefully consider power consumption aspects to maximize the battery life. Actuators for mobile devices are limited by the amount of energy required to drive them. A typical motion sensor can use as little as 25  $\mu$ A whilst a typical vibration motor will consume 74 mA (3000 times more current). Another example is the use of magneto/electro-rheological fluids for haptic feedback. Magneto/electro-rheological fluids employ Ferro fluid and magnets provide computer controlled physical shape of the Ferro fluid. The amount of power to maintain a shape either by using an electric charge to align the material in the Ferro fluid or a magnetic field to align the material is currently prohibitive. New lower power approaches are needed to make these haptic devices viable. Similarly, most common actuators that provide linear movement also have prohibitive power requirements.

### Size and Weight

Actuators often need to work against human muscles in order to provide haptic feedback. This requires not only the current required to drive the device but also the physical size to be able to generate the force. Smaller actuators just do not provide the torque to provide a sufficient force to the users to have a gratifying haptic effect.

### Mechanical Complexity

Actuators tend to be mechanical in nature as they are attempting to impact on the real world. This requires construction of physical devices that can pull, push, move, glow, change, heat or cool. These effects are not cheap in size or power usage and tend to be complicated, as the device needs to enact some physical principle in order to achieve the desired result.

In particular, actuators that move and change usually require mechanical crafting. This crafting needs to be small enough as to not get in the way, but strong enough to not be easily broken or confounded in operation. For instance, to move the actuator you may use a magnetic field to turn a shaft, cogs to gear, or sliders to relocate the force. These effects are rarely cheap to produce, especially at the scale of a wearable computer where there is a stringent power budget.

## 5. Future of Wearable Actuators

A compelling example can be taken by looking at science fiction movies for inspiration. For instance the recent Batman movies make extensive use of worn actuators such as a cloth that can form rigid structures when electric current is applied. This leads to many possibilities on shape changing effects, such as the cape that turns into wings from the movie above.

Recently, interest has developed using actuation on armor for soldiers. These actuation-based devices divide into two basic approaches, the first being a passive approach that relies on physical properties to distribute energy such as shear thickening fluids. These fluids use a property that makes the material harden in proportion to the energy applied. These do not require energy or control however, the second approach uses a more active approach. An example for the second approach is the electro-rheological approach that activates the armor when the soldier is under attack. Whilst initial versions of this material used significant amounts of power to produce weaker structures each generation is improving significantly. Currently the best power efficiency is about 16A per square meter[6]. Unfortunately that is still high for wearable devices but is not unreachable with battery technology improvements.

Looking further into the future the Hollodeck is a great example of how the ultimate actuators might be employed to provide full computer control of matter. This vision was described in detail by Sutherland [7] where he said “The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal”. Although this level of computer controlled matter will require significant technological advances, there are many smaller steps we can take to work towards this goal. The Holy Grail for actuated devices is a device that can form any shape on demand. This would allow the user to build tools on demand on their body. This would require a device that

can move or create molecules that could be moved into place to “replicate” the required device. We are not close to that as yet but there are still significant scientific challenges that must be addressed before this vision can become reality; the use of actuators and the materials such as magneto/electro-rheological fluids look promising for future approaches.

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# Towards Industrialisation of Augmented Reality

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## Abstract

Augmented reality (AR) is a field with a long history. Yet, recent applications are very different from the early research in AR; some are poised to completely transform the way humans work in the modern world. Despite the widespread applications of AR, the concept of AR is slowly emerging into popular consciousness only in the past few years. There is a large variety of research on all parts of any AR system, including object tracking, information presentation and user interaction. This paper investigates research and applications in AR and from these synthesises possible future research for industrialisation.

## 1. Introduction

Augmented Reality (AR) has been around since as early as 1992 [1]. Today it is used in a vast range of applications. Yet, it is not everyday knowledge.

The potentials of modern AR research have been glimpsed. In smartphones, camera images, location data from the built-in GPS and online landmark information are combined to display relevant destinations. In advertising, context-specific marketing content is delivered via overlays of visual material over a mobile camera view of a real-world place.

Given its technologies and their applications, what is holding back “augmented reality”? What research directions could help industrialise AR? The term “augmented reality” has hitherto deliberately not been explicitly defined. To resolve the definition of AR, its origins must be considered.

## 2. “Augmented Reality”

Usage of the term “augmented reality” has been evolving since Azuma conducted a survey of AR in 1997 [2] in an attempt to catalogue AR research and applications. In the survey, augmented reality was treated as a mixture of the real and the virtual so that the user could perceive the real world with virtual

objects supplementing the user’s view of the real world. The survey covered AR as systems that (1) combined real and virtual, (2) were interactive in real time and (3) registered in 3-D. Azuma also expanded on the said characteristics and captured the field of AR research in the following key traits:

- Augmentation of one or more senses
- Optical vs. video view
- Visual focus and contrast
- Portability

### 2.1. Definition

To acknowledge the advance of technology for nearly two decades, the definition of augmented reality in research needs to be revised. More importantly, the core of AR needs to be generalised into the following:

1. Supplements real world experience
2. Directly interactive in real time
3. Augments objects contextually

These characteristics represent the foreseeable goal of AR research in general. This definition covers current AR as defined by the technologies involved as well as approaches and techniques employed as fit these criteria even if the augmentation is not strictly sensory (e.g. application of contextual information).

This definition is by no means a future-proof one; however, it is sufficiently general for the technology of today and the foreseeable near future. Critically, augmented reality being an experiential field, the scope of this definition addresses the user-centred component of AR applications particularly in relation to the intended audience of the application.

### 2.2. Research and applications

AR research covers a vast number of interdependent fields. Most of these research fields tackle specific problems encountered in application.

**2.2.1. Registration and tracking.** The arguably biggest problem specific to the way AR technology works is that of object registration and tracking. Most current approaches require some modification to the environment. Vision-based technology conventionally uses predefined markers to register the projection frame; consequently, when view of one or more markers is obstructed, this system is no longer able to register the environment [3]. Nonetheless, advances in object recognition have enabled detection and tracking of known visual features (e.g. hand) and geometrical shapes to establish coordinate systems [4][5].

To reduce the error in these approaches, recent work on multi-sensor fusion attempts to combine the input from multiple sensing mechanisms to limit the influence of error from any one source [6]. This system effectively evaluates all sensor input, assesses the degree of favourable detail from each type and uses the granularity from fine sensors to complement the robustness of coarse sensors [7].

**2.2.2. Presentation.** In AR presentation, two major ideas seem to be in play: presentation directly to the user's senses (i.e. without interacting with the environment), and presentation on the environment by augmenting it with graphics or other signals.

Popular visual display technologies include LCD, HUD and HMD. Displays like the LCD are limited by the application in the physical dimensions of required space and the type of information to be presented. Displays such as the HMD create a virtual space using depth perception to deal with inaccessible physical dimensions [8].

Large amounts of information must be filtered as contextually relevant. Livingston et al. [9] pointed out that too much or incoherent information presented at any one time can cause information overload. In military engagements, the key is limiting information addition to preserve or increase situation awareness.

**2.2.3. Interaction.** In practice, the flipside of presentation design in an AR application is user interaction design. Efforts to make AR intuitive gave rise to principles collectively known as Tangible AR [10], in which interaction with a virtual object is based on the metaphor of a matching real object. The goal is to form intuitive gestures that can be mapped to understandable virtual tasks one-to-one. This metaphor can be expanded to multimodal interaction, such as speech, head pose and haptics [3], and varied depending on the size of the virtual object [11].

Information authoring is another key component in AR, generating augmented content for use. Common

authoring tasks such as 3D modelling can be enhanced by giving designers an extra dimension to work with [12]. The mobility of modern AR devices also enables the user to capture the real world and augment it on the go [13].

**2.2.4. Ubiquitous AR.** There are two properties of any ubiquitous information system: the architecture must be organic and interact with a variety of sources and sinks, and contained information must entail contextually relevant subsets.

The Linked Open Data (LOD) cloud [14] contains numerous data providers on a vast range of popular subjects available on the Web. The Web 2.0 infrastructure can provide the necessary multimedia mechanisms for content delivery [15].

Ajanki et al. [16] have designed an AR platform that uses contextual clues to directly extract relevant topics and fetch requested information for augmentation overlay. Mendez and Schmalstieg [17] have worked on an adaptive system that separates general qualitative contextual attributes from object properties in order to organise more abstract concepts. When this abstraction of contextual information is combined with an event system [18], the dynamics of the physical world can be modelled in the ubiquitous AR system.

### 3. Future research

In light of the current topics of research, there are a number of gaps to fill.

#### 3.1. Pervasive object tagging

In current AR tracking approaches, once the coordinate system has been acquired, tracking of the environment and objects in it is still largely vision-based. This characteristic stems from the need in many AR applications to register previously unrecognised, arbitrary objects. However, this approach can often be computationally expensive in an outdoors environment.

Developments in RFID technologies have allowed for automatic object tracking in factories and along supply chains. Similar approaches could be applied to globally tag systems of objects. The tags could then be used in registration and tracking for AR both as a stopgap for current computational limitations and as low-cost level of detail for an AR system to identify objects with.

#### 3.2. Cognitive study of augmented objects

Usually, AR research is entirely focused on either augmenting real objects or adding completely virtual

objects to the real world. When both are discussed in a body of research, there is almost no distinguishing between virtual objects and augmented real objects.

AR research has been about adding a virtual dimension to the physical world. So far, purely virtual objects have been associated with creative activities that construct the virtual object from scratch or simulations treating the virtual as real. Augmentations to real objects tend to function merely as assistive facilities. More study into this gap can perhaps better define the full extent of the cognitive function of virtual augmentations and extend the role of augmented objects into real objects to bridge this gap.

### 3.3. Accessibility design

The human senses allow perception of and interaction with the world. The disabled lack some of these faculties, so modern assistive and prosthetic technology effectively helps regain one or more of these faculties. In a similar way, AR augments sensory experience where existing senses are insufficient.

However, there has been precious little work on designing interfaces to augment the sensory experience of the disabled. It should theoretically be possible to design AR systems that do not require the comprehensive use of visual, auditory or speech abilities. In a world where the disabled are making ever more contributions, using AR to supplant their senses alleviates part of the physical hindrance.

### 3.4. Integration of presentation and interaction

The artificial boundary between presentation and interaction limits AR subsystems. Several factors affect both presentation and interaction: contextual relevance is determined by user interaction with the system and by environmental factors, and in turn affects the relevance of information continually received and how this information is presented, which then influences user interaction.

Thus, for a contextual information model to be viable (especially in the field of ubiquitous AR), presentation and interaction must form one indivisible aspect of an AR system. Current AR research treats these techniques in terms their enabling technologies. However, it is becoming increasingly apparent that effective AR requires information to constantly flow back and forth between the presently disparate presentation subsystems and interactions subsystems.

Research is needed to integrate information flow in registration and tracking with user interaction at optimal points of intersection. This will lead to a better

ability of AR systems to fully exploit general contextual information as atomic, autonomous agents.

### 3.5. Integration of user and environment

While user interaction in AR is nominally considered a uniform characteristic, the types of interactions vary across different applications. Modern AR research and applications are dominated by an overwhelming focus on the human interaction component. Recent applications have been more about improving on previous user interface design by making it intuitive than exploring other aspects of the relationship between the user and the environment.

Further work needs to be done on cognitive interaction between a real environment and its virtual counterpart, particularly when one of them is partially or completely occluded. This work will be significant in mapping where the real ends and the virtual begins, and thus how to best present AR that integrates the virtual experience into reality.

This will result in a clear, general, non-technological understanding of AR presentation methods and the criteria for choosing a particular class of augmentation techniques. This will in turn determine the need (or absence thereof) for specific tracking and sensing systems and ultimately a precise knowledge of the necessary degree of separation between the user and the environment for different types of applications.

## 4. Conclusion

In the same way that Azuma in 1997 [2] did not include 3D stereoscopic displays, this paper has not addressed certain emerging technologies. Yoshida et al. [19] have created a working prototype of glasses-free 360° holographic display. Iwamoto et al. [20] have developed an ultrasound tactile display that provides tactile feedback in midair by generating acoustic radiation pressure. Lingley et al. [21] have developed wireless contact lens displays. When these developments eventually mature, a virtual object can just about be a real object.

Other possibilities are still waiting for yet untheorised scientific breakthroughs. The AR of today adds to the user's sensory experience. When the science and technology of tomorrow are able to isolate and study extrasensory experiences (e.g. intuition), AR will revolutionise interaction design. The cognitive principles underlying the specific value added by visual overlays will completely reformulate the concept of augmenting reality.

In many ways, the bulk of AR research and applications today forms transitional technologies.

These are the stepping stones toward the true potentials of AR and its ability to comprehensively augment the physical reality.

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