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Multimodal Machines Makes Military Move

A visiotactile artefact for augmented soldier communication

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Abstract

Soldiers work in an extreme and hostile environment, where their survival is dependent on an information advantage as well as on communication within in their own group and with other groups. Their communication is conducted in a surrounding where noise from weapons often overwhelms a voice and camouflage and uneven terrain diminishes the usability of visual contact methods as hand signals. Their ears and eyes are also used as the primary tool to detect any threat from a potential enemy and are therefore cognitively strained right from the beginning.

By introducing tactile perception as an alternative source of communication, we hope that the overall performance of a soldier can increase through decreasing the cognitive load they presently endure. Through the development and testing of a prototype for such a tactile interface thought to augment some of the present communicative ways, we have tried to answer the question if tactile information is usable within the military context.

Methods:
Bodystorming, laboratory user studies, Prototyping.

Keywords:
Tactile interfaces, comfort, prototyping, vibrotactile, display, Ubiquitous Computing, Calm Technology, Wearable Computers.

The report is written in English

Sammanfattning

Soldater arbetar i en extrem och hotfull miljö, där deras överlevnad hänger på ett informationsövertag och en förmåga att kommunicera inom och utom gruppen. Deras kommunikation sker i en omgivning där vapenbuller ofta överröstar deras röster och kamouflage och ojämn terräng försvårar användandet av visuella kontaktmetoder som handsignaler. Deras ögon och öron är dessutom det primära verktyget för att upptäcka hot från en potentiell fiende och är därför kognitivt belastade redan från början.

Genom att introducera taktil perception som en alternativ källa för kommunikation hoppas vi att kunna förbättra soldatens prestation genom att minska den kognitiva belastning de för närvarande har. Vi har försökt att besvara frågan om taktil information är användbar inom den militära kontexten genom att utveckla och testa en prototyp för ett taktilt gränssnitt.

Metoder:
Bodystorming, laboratoriebaserade användartester, Prototyping.

Nyckelord:
Tactile interfaces, comfort, prototyping, vibrotactile, display, Ubiquitous Computing, Calm Technology, Wearable Computers.

The report is written in English

The picture shows the last prototype of PalpEye

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Gothenburg 2004-05-06

”When I examine myself and my methods of thought, I come to the conclusion that the gift of fantasy has meant more to me than any talent for abstract, positive thinking.”
Albert Einstein

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1 Introduction

Peacocks do it! Howlers do it! Do you do it?

The male peacocks and howler monkeys are two very different species, seemingly without any similarities. They have, however at least one thing in common, a very obvious way to attract attention.

The howler monkey's impressive voice permeate the dense foliage of the jungle, carrying his note of presence far and wide around, while the male peacock flaunt his extravagant tail feathers in order to get the attention of a lovely female or to ward off any unwanted competition. These two communication skills are quite effective, but not always practical. Being very extrovert and distinct in your communication does attract the attention of, not only your own species; everyone else tend to notice you as well, including potential predators.

Today's soldiers' lives in much the same world; imagine trying to talk through the loud clatter of a machine gun, or the deep booming of artillery, and it's easy to see that it is a good time being a howler. Another way of communicating to overcome the noise problem is to use sign language, like the peacock.

Using visual communication draws its own problems. Distances, bad light, uneven terrain and camouflage clothing diminishes visibility and can make a signaling person quite hard to detect, for both friend and foe. Being a peacock in this situation could augment the visual cues, but how do you ensure that only the right pair of eyes sees the signal? You do not wish to become the target of an enemy's bullet. When considering the tactical advantage of silence and stealth, the military's current ways of communication by vision and hearing is, in its essence, a contradiction in terms. Every sound or movement will increase the risk of being detected; still they need to communicate between each other without alerting the enemy.

The human being has five senses that we use to ensure our survival and prosperity. As a part of our survival strategy we have created tools to aid our rather dull nails and teeth. One of the latest tools modern man has invented is the computer. With its powerful computational skills we have now created a possibility to sum up, extend and externalize our knowledge for others to share in an outer manifestation, an artefact which in it self actively can contribute to changing of our knowledge of the world.

A common trait of all our tools is that we use it to manipulate some part of our environment. Adding physical force at one end we can transform the motion into a slightly different power, for example cutting a piece of bread with a knife. A computer also needs some sort of input to generate an output. Instead of using a traditional handle or edge, the computer outputs have been vision or audio, while inputs have, to this day, been mostly tactile with a very limited number of tools to our aid, such as a keyboard or a mouse. These techniques of using a computer work quite well in an environment as offices or homes, where we can control our surroundings to minimize any disturbances. One needs to understand that a lot is assumed about the context in which an artefact is used. Developers often take the context for granted when designing an application or a product and that is a problem. The context is complex and dynamic and in a military environment this is very obvious.

The surrounding of the military is probably as far from "a common day at the office" as you can imagine. Weather, wind, extreme temperatures, and an acute risk of getting hurt or even killed, are factors that any soldier risk. When designing for computer interaction with this extreme environment in mind, we have chosen to extend our search for interaction techniques outside the traditional ones. Integrating computers in this environment does not only demand highly durable electronics, it also requires an interface that does not add to the soldiers cognitive strain.

Norman (1988), states that tools, whether they are computer based or not, should in an ideal world tell us what they are for. The tools should also help us in our work, not control our work progress or force us to a process or methodology that, due to context or goals, comes unnatural to us. By designing tools with an understanding of the context and tasks that the user is working within, we can implement affordances (cues to the manipulations that is possible with a design), real or perceived, within the system. Examples on such an affordance relates to the use of coffee cup. The handle invites a user to grab it, to pour fluid into the hollow. The handle also gives a clue about the temperature of the fluid that can be used. Using affordances could make the tool seemingly custom made for each user, therefore creating a system which the user appreciates, understands and, above all, uses in his everyday work (Karat et al, 2000).

We all live in an environment that is constantly pounding information over our heads. In our daily lives we have learnt not to react to the abundance of messages reaching to us from news alerts or commercials in papers, TV or radio, since we have learnt that most of the messages does not concern us or would make a difference in our survival.

A soldier's survival is dependant on information. Battle is seldom won by sheer overpowering force; the side that has the best intelligence can gather more accurate information and thus concentrate their efforts on areas where they can get the most impact. Gathering information is one thing, distributing it to the right person is an entirely different matter. Using the normal ways of communication with visual or auditory commands may work very well in a calm environment, but how do you ensure that everybody have gotten the information when the chaos of battle is raging around you?

In this thesis, tactile perception is the locus of interest, as we believe that when processing an ever increasing amount information, the extreme task environment of a soldier have reached the limit of what a soldier can process within his visual perceptive limits. His task environment puts great demands on concentration, focus and outbound attention as his eyes and ears are the main means to navigate and locate objects and adversaries.

In a combination with a visual display we try to investigate if tactile perception can be used as an information channel in a military context in general and the combat equipped dismounted soldier in particular. Bendable displays are an emerging technology that can give a wider spectrum of use for displays. They can be embedded into clothing and shaped to fit around curved surfaces, and will be able to withstand different mechanical strains that aren't possible with conventional LCD.

1.1 Present environment

1.1.1 The context of MARKUS

MARKUS (Markstridsutrustad soldat) is the name of the combat equipped dismounted soldier in a study made by the Swedish military to find the demands and solutions of the future soldier around the year 2010.

Our society's increasing globalization and new, emerging sources of threats, for example terrorism, has rendered the Swedish National Defense with new demands of adaptation. The Swedish National Defense now needs to be able to work towards a wide range of government facilities and organizations, both within Sweden as well as on an international scale. To achieve these new goals a Network Based Defense -NBD- [4] is under development. NBD creates a foundation for a new kind of flexible defense, an easier way to adapt to new threats, tasks or technology.

The key words in NBD are cooperation and modality, between single systems, between troops (this is MARKUS domain), the army, the navy and air force as well as between the military and civilians. NBD is thought to facilitate the understanding and communication between the cooperating parties and enable usage of each other's resources and knowledge. It is also thought to improves tactical issues through a novel way of sharing information, by that the officer's order and intentions are communicated at an earlier stage.

There is no deadline when NBD should be finished; since NBD is supposed to be an ongoing process based upon basic functions within the military, instead of the typical troop and its system.

As a part of NBD, MARKUS is thought to focus on the soldier at group level and his equipment. It is important to stress that MARKUS is not thought to be the new super soldier; instead the focus is on finding good solutions for subsystems which later on will be integrated into a larger system.

The new technology on the rise within, for example optronics and electronics, has given the MARKUS- soldier a new, high-tech, possibility to solve his tasks in a war situation in a better way than his adversaries.

In order to design an appliance that fit into MARKUS gear, there is a need to understand the philosophy behind it. MARKUS abilities are described. In its condensed form, MARKUS need an advantage in; protection from different weapons and detection as well as an increased knowledge of the task environment (surroundings and situations).

1.2 Purpose and goals

We have named our project PalpEye. The name PalpEye defines the function of the artefact as well as its mobility as it stems from the word "palp" and "eye" and is a travesty on PalmPilot. A palp is the sensing organ of many insects, for example ants. In a wider perspective both electronic textiles and wearable computers are foundations to PalpEye where visual and tactile perception is considered to be the main input channels of information.

The idea stemmed from a discussion with the personnel at the MARKUS group and there were an interest in different methods of communications. From this PalpEye emerged.

With PalpEye, tactile perception is revised. Humans have a limit in how much information they can process. That limit, we believe, can be dispersed between different perceptual systems. The use of more sensory channels can augment the coding of information without overloading any of the perceptual systems used.

The goal of PalpEye is that of being in the periphery until it is needed; only to crave attention when something changes, and to be an augmentation and support of a soldier's other perceptive channels already used. The following description of the tactile perception system will therefore be concentrated on the cutaneous perception which resides in the skin.

PalpEye is a combination of a tactile and visual user interface that in its first generation will present a very limited amount of data.

The collaboration with MSS (Markstridsskolan) in Kvarn, resulted in a quest to find out the possibilities to implement a tactile user interface into the gear which is used by soldiers. MSS also had wonderings about the use of bendable displays and these questions are regarded and analyzed in this report.

1.3 Problem space

For this thesis and its problem space, we have set up a few questions concerning PalpEye and the task environment in which it should reside. This report will focus on two central questions;

- *Can tactile manipulation be of use within military information applications?*

- *What general technical specifications could a visiotactile artefact incorporate?*

There are several problems in creating a display using tactile perception:
Are there any natural metaphors to represent phenomena?
Where is the best location for tactile instruments on the body?
Which information is best suited to be represented by tactile feedback?
Which requirements does PalpEye need to meet to function properly?
Can the use of tactile perception be enough in order to present information or is a combination of different perceptual channels (multimodal) preferred?

The second question has been broken down into these:
What are the demands from the soldiers which have to be considered when designing PalpEye?
How does tactile perception function as an information channel? Is it possible and how do we design it?
Can we produce bendable display technology and is it usable within extreme environments?
What are the main available tactor (tactile stimulus) technologies today and what can we expect of the future?
What different display technologies are available and what are their different limitations?
What are the smallest amount of technology and functionality that can be used to create a testable prototype for PalpEye?

1.4 Boundaries

To set some boundaries around this project, we have decided to only develop a potential output device, based on cutaneous perception in combination with a visual display. We have chosen not to put any effort in developing a fully functional input device since the potential input is very dependant on technology, studies and external decisions of the Swedish Army.

The reason for excluding haptics, the fine-tuned tactile perception of the hands which has a greater exactness in perception of symbols, is that our user group, the soldiers, needs to have their hands free for solving the tasks they are set out to do and have their focus on other things.

Further, we have chosen to use only standard COTS (Commercial Of The Shelf)-technology and materials, or materials that are provided from the Swedish Army. This choice has had its advantages as well as its downsides. To the advantages is that it is standard parts and as such easier to find and purchase, it is for the most part documented and not least relatively cheap. On the downside is that as standard parts, they not always exactly fit to what was thought of in the beginning. We chose materials that was close enough to give a good enough representation of our ideas although it does not fully satisfy all of our needs.

2 Background

Some of the research that have been made regarding tactile interfaces an d future soldier systems serve as a foundation for the understanding of the problem space that we are confronted with. A theoretical framework needs to be adopted in order to for us to communicate between each other using the same vocabulary.

2.1 Related works

2.1.1 Tactile Displays

The development of tactile wearable artefacts has been going on for centuries. One of the first documented tactile interfaces was in a clock embedded in Queen Elisabeths (1533-1603) ring, using a needle that scratched the bearer every whole hour (Martin, 2002). More resent tactile interfaces are the vibrators used in beepers and mobile phones to augment the carrier on an incoming call (Ljungstrand, 2001). Toney et. al (2003) created a business suit embedded with vibrators in the shoulder pads which in turn used different vibrating patterns in order to communicate certain symbols. Other applications that use tactile channels are force feedback Joysticks for computer games to enhance the gaming experience.

Other vibrotactile interfaces have been made by McGuirl and Sarter (2001) incorporating tactors (some technology to induce tactile stimuli) on the inside of the forearm. They wanted to give cues about icing. The result showed that multimodal interfaces using a tactile component helps the user identify and keeping multiple tasks at hand. As early as 1988, Zlotnik (1988) tried to transform auditory signals into mechanical or electrical tactile stimulation for fighter pilots. Zlotnik also identified that auditory and visual perception had reached a limit in their ability to process information and there was a need to enable other perceptual strengths, such as the tactile sense. A conclusion from all research on tactile interfaces is that it has potential to the user but also that many questions still remain in finding out about the tactile perception and the applications needed.

Other technologies have been used creating tactors besides vibrotactile, such as pneumatic (Yobas et al, 2001), electrostatic (Jungmann & Schlaak, (2001), electrotactile (Tang & Beebe, 2003) and heat and cold (Kron & Schmidt, 2003).. There are several different human skin receptors that all have its own sensing range (Shiffman, 1994) and have been used for different tactor technologies. Mostly Braille displays used for people with disabilities in their sight and similar displays for the fingers have been developed (Moy et. al., 2000), due to the sensitivity and concentration of skin receptors on the fingers.

2.1.2 Future Soldier Systems

Future soldier systems are being developed by many countries. The dismounted soldier works on the ground, with little armor surrounding him. Besides this, the dismounted soldier has limitations on the amount of gear that can be carried.

The Australian Army's future soldier systems, called Land 125 Soldier Combat System (formerly "Wundurra" (the aboriginal word for Warrior)), aims to optimize the combat solider through the incorporation of appropriate technologies, such as intra-section radios, night vision and helmet mounted display. In France there is a project called FELIN (Fantassin à Equipement et Liaison Integrées) that will be operational 2007. In order to enhance the efficiency of the soldier a set of devices have been developed with very careful limitations. One problem is the weight of all equipment, thus the FELIN project wishes to limit its load at 25kg. The soldier has got a radio link, a computer and a camera on his weapon (allowing him to open fire from cover), which is also incorporated into Land Warrior. The display is done with a monocular HMD. The British FIST (Future Integrated Soldier Technologies) [1] made a series of tests trying to determine if the soldier could access information either 'Head Up' (in a helmet display), 'Head Down' (on a wrist mounted display), via a palmtop computer or if necessary a map. Findings resulted in that there is no scope for enhancing soldier performance through the provision of tactical information unless the soldier can access information "on the move". US Forces Land Warrior is one of the largest "future integrated soldier systems" to this date (Zieniewicz et. al., 2002) and has been tested on several occasions. When incorporating new technology into the world of the dismounted soldier it also calls for an adaptation of tactics, techniques and procedures. Several other systems are being designed and NATO tries to establish standards for the interoperability of different systems within NATO.

2.2 Theoretical framework

For the purpose of understaning the framwork which we work in developing a tactile interface there is a need to shortly describe some of the theoretical ground upon which we rest. The use of a human centered development cycle is important since we deal with users and design for the user, giving an unknown impact upon their context of use. Therefore it is essential to adopt a humble attitude towards the design of wearable computers.

The field of Human Computer Interaction (HCI) and Interaction design spans widely from psychology to technology. Central in all HCI work is the human being and her ability to act, react, communicate and cooperate with her surroundings and technology. What differs then the interaction design from "common" design? Well, one can easily point out two factors, each basic in an interaction designer's work.

First, in all interaction design the user is always in focus, not only as a mere user of the product itself, but also as a member and owner of the design process concluding in the product/system. Further on, the interaction design uses a lager context where everything that could impact the system or user in their daily work, counts, from the graphical interface, aesthetics, and functionality to how it will be perceived and affect the users in their social identity. Secondly, an interaction designer's main design material is the computer or information derivable from some electronics in one for or the other.

In the following chapter, we have tried to give an overview of the theoretical background that is relevant to this thesis. The overview is not to be perceived as a complete register, merely an example over relevant areas and some of the theories are active in each area.

2.2.1 Ubiquitous Computing

For thirty years, most interface design, and most computer design, has been headed down the path of the "dramatic" machine. Its highest ideal is to make a computer so exciting, so wonderful, so interesting, that we wouldn't want to be without it. A less-travelled path is, let's call it the one of the "invisible" computer; its highest ideal is to make a computer so embedded, so fitting, so natural, that we use it without even thinking about it.

In computing, three "waves" is a quite common notion when describing computer development over the years.. First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing (Weiser, 1991), or the age of calm technology, when technology recedes into the background of our lives. This second path is by some believed to dominate the world of computing in the next twenty years. It will not be easy; very little of our current systems infrastructure will survive.

2.2.2 Calm technology

Tradiotionally technology has been used as a tool that enhances and augment human performance. According to Weiser (1991) "Computers...should give us more information, but in ways that are helpful, not intrusive and irritating". Weiser calls this idea "calm technology", which has become a central and basic conception within this research field and in our thesis.

Weiser (1991) argues that the idea seems contradictory, even nonsensical. Consider how much technology is involved in making a fine writing pen or a comfortable pair of shoes, or in delivering a newspaper to your door. Why are such things comfortable, while the computer is so irritating? One basic idea is that the difference lies in how they engage our attention. When driving a car, for example, the focus lies on the road or the radio. Engine noise is at the periphery of attention — until it changes suddenly, and then we're instantly attuned to it.

"Calm" or "encalming" computers would deliver information in the same way, Weiser (1991) suggests. The information would be present in the background until needed, move to center stage when needed, then fade to the background again — something like having the television on with the sound turned down until a "news alert" is broadcast.

2.2.3 Wearable computers

Computers are known to be big, grey boxes that often provoke and anger their user due to the odd behaviour they present. Others know computers for the valuable asset that they can be for developing advanced data processing tools.

Researchers now try to make this personal computer fitted for your everyday life, being there for and under the control of the user. Mobile phones and PDA's are examples of artefacts that have been made mobile and tried to be woven into the lives of people. Taken from the use of mobile computers is also the concept of computers that are invisible, unobtrusive and embedded into our lives by weaving them into clothing or fitting them into small wearable devices that becomes natural and transparent for the wearer to use. One of the first wearable computers that were constructed is the wristwatch (Martin, 2002). Nowadays a wristwatch is for many a necessity in their life and the philosophy of wearable computing is to fulfill the same need. Watches were thought of as unwanted and pointless, but history has shown us another picture (Martin, 2002).

Wearable computers are being designed for all kinds of purposes and with a whole different infrastructure from the computers we know today. The aim is to create the truly personal computer, an artefact that can be so closely integrated with the user that it becomes invisible. Falk et al. (1999) stress the importance that the "wearable computer is a computational device in the user's personal and private control; the user carries the device on his or her body and is the only person to interact with it".

With PalpEye we are trying to merge the physical space with digital technology and still making it natural to use.

2.2.4 Context awareness

"With eight tentacles and the ability to shift colors rapidly, the intelligent octopus is a master at learning, adapting to, and controlling its environment. To improve their coverage, reliability, and usability, multimodal interfaces likewise are being designed that can automatically learn and adapt to important user, task, and environmental parameters" (Oviatt et al. 2004)

It's easier to present information than knowing what information is needed at a certain time (Brown & Jones, 2001). Wearable Computers differs in use from stationary computers, where the user is not only in motion, but in an ever-changing environment that requires a difference in handling and attention. What differs in context is that the recipient's situation in mobile use is that he may not always have the ability to retrieve information due to the task at hand or environmental factors.

When designing mobile computers used within a group of people there is a need for the artefact to have an awareness of the user's situation. The awareness should be used to assure that the retrieval of information is without interrupting or interfering a task as long as possible. Users of mobile phones have a possibility to create different profiles as to filter incoming information.

If sensors and appropriate algorithms are applied to mobile devices, awareness can be created in the artefact itself, creating an enhanced functionality relieving the user from further tasks and interpreting context information. An ideal artefact can in this case create a homeostasis between groupware users and sharing of information. Urnes et.al. (2001) defines context awareness as "devices that gather contextual knowledge about the users and operating environment".

Since sensors are becoming cheaper and smaller, context-aware wearable computers are becoming increasingly interesting for researchers. According to Brown and Jones (2001) a key component in many of the applications regarding context aware computers are the context-aware retrieval (CAR) of information. Efficiency is an important factor in CAR since late information is useless.

In a military application where the right information in the right time is crucial there are two fields that can be adopted to CAR; namely Information Retrieval (IR) and Information Filtering (IF). The information retrieval and - filtering can enhance the effectiveness and efficiency of information given to a mobile user. Further Brown and Jones argue that IF and IR research has focused on the weighting of documents most urgent to the users in a certain time. IR and IF has to the time of Brown and Jones report not been concerned with CAR applications.

2.2.5 Human Factors

Human limitations regarding cognitive and ergonomic factors are important to deal with. Some of the more central issues for the development of a "near skin" wearable computer is the tactile perception and comfort. Also regarded is the limitations of human memory due to the use of tactile data as a communication channel. We will only outline some of the issues that could be important to the development of a tactile interface and wearable computer. There is more research needed to fully understand the impact of wearable computers in a military context.

2.2.5.1 A Theory of Tactile Perception

The skin is, by far, the largest organ in the human organism. It serves both as a protective boundary between the organism and the environment, and as a sensory organ which gives important clues about what is directly adjacent to the body, especially the presence of potential harmful stimuli. There are three identified "qualities" of cutaneous sensitivity, pressure (also called touch, contact, tactual or tactile stimuli), temperature (warm or cold) and pain. (Shiffman, 1994). The sense of touch is probably the most complex of all our sense modalities in all the different types of receptors spread over a large area. Our other senses are located in a fairly small area, such as the eyes, nose, tongue and ears. The sense of touch can according to Caldwell et. al. (1996) be divided into three systems:

Visceral sensibility – sensations associated with the internal organs.
Deep sensibility – sensations associated with joints and skeleton muscles.
Superficial sensibility – sensations associated with the skin.

It's only the latter two systems that have some kind of interaction with the outer world, and Caldwell et. al. (1996) argue that the deep and superficial system are often clustered together as to form the haptic system. Its in turn divided into the kinaesthetic and cutaneous system. The kinaesthetic system gives sensation about posture as well as positions and movement of the body parts. The cutaneous sensor system is built up by several different mechanoreceptors situated in the different layers of the skin. When stimuli are applied to the skin, the mechanoreceptors encode and forwards information of the mechanical deformation, via two large pathways (the dorsal column-medial lemniscal and the anterolateral system), to the brain. There should be noted that all regions of the skin does not have the same sensitivity to all forms of cutaneous stimuli, some areas may be more sensitive to a specific stimuli than others and vice versa. Several types of receptors are so far identified (Hatwell, Y., 2003, Shiffman, 1994)

I. Meissner corpuscles

- Small, localized receptive fields (High spatial accuracy).
- Rapid adaptation (active during the initial contact with the stimulus.
- Codes the movements at the surface of the skin (a held glass sliding in the hand).

II. Merkel disc

- Small, localized receptive fields.
- Slow adaptation (active during the entire contact with the stimulus).
- Codes information on the spatial shape and texture of the stimuli (raised letters or Braille).

III. Pacinian corpuscles

- Large and less localized receptive fields (Low spatial accuracy).
- Rapid adaptation
- Codes the temporal attributes of the stimulus (such as the vibration of a tool manipulated by the hand

IV. Ruffini endings

- Large and less localized receptive fields.
- Slow adaptation
- Encodes warmth

V. Krause end bulbs

- Encodes cold

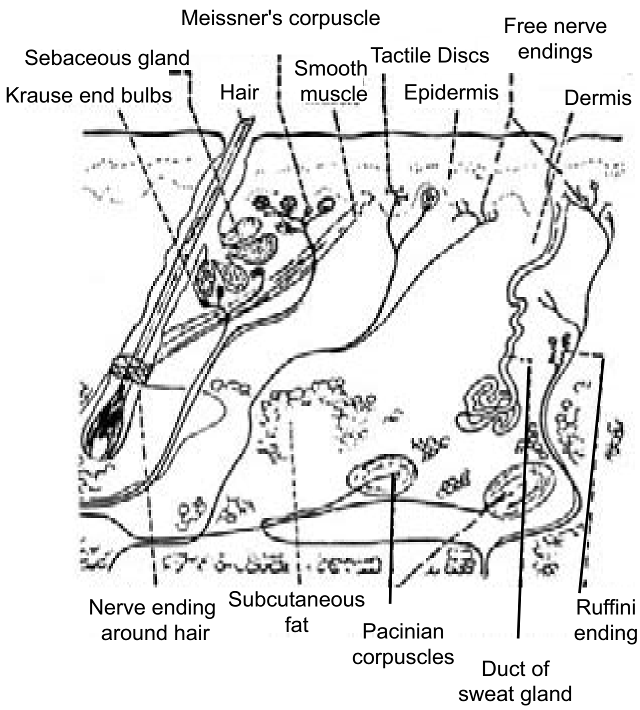


Figure 2.1 Vertical Crossection of hairy skin (Based on Gregory & Colman, 1994, p. 34)

Hairy skin has yet another sensory organ, basket cells, situated around the root of each hair. Touch differs from vision and hearing in that it depends on contact and that its receptors are spread over the whole body. Because of this property, the tactile perceptual field is limited to the zone of contact with objects. There are two kinds of tactile perception, a passive tactile perception and an active. The passive perception or cutaneous perception, occurs when stimuli is applied to an “immobile” part of the body, such as a leg. Since the leg lacks a fine-tuned, exploratory possibility, the perceptual field has the exact dimensions of the surface of the skin in contact with stimuli and thus limits the tactual perceptual capacity of this body part. The active perception, also called haptic perception, joins the cutaneous perception with an exploratory ability and precise movement. This enables the moderation of the size of the perceptual field at will, depending on what to explore. The perceptual field can be as small as a fingertip and grow as large as both hands associated to movements of the arms. (Hatwell, 2003)

Pressure and sensitivity.

The skin is very sensitive to light pressure. Under ideal condition the displacement of the skin less than 0,001 mm, can be perceived as a stimulation of touch, although the amount of stimuli needed to achieve such a sensation differs between body parts (Shiffman, 1994). The two point threshold is the smallest separation of two, discrete but adjacent, points of stimulation on the skin which is perceived as two distinctive impressions of touch. As of almost all stimuli, the mobile parts of the human body are more sensitive and have lower two point thresholds. Notable is that this sensitivity also depends on what side of the body the stimuli is applied. Generally the right side is more sensitive than the left.

Under continuous tactile stimuli the body adapts and tends to ignore or decrease its attention to the stimuli (Shiffman, 1994). For example, even after a short time the clothes on our body are no longer felt, nor our wristwatches or jewellery. This adaptation to stimuli varies with a number of factors, particularly the size, intensity and what region of skin under continuous contact. The sensitivity is quickly restored though, when the source of stimuli is moved or abruptly changed in its character.

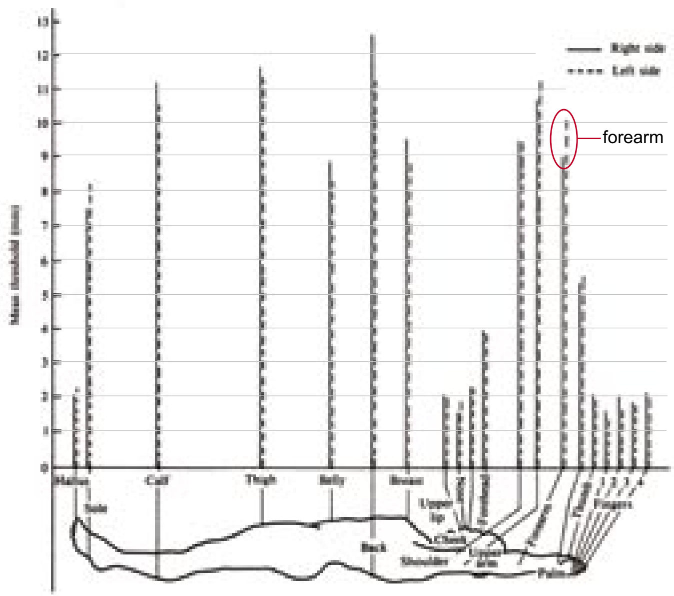


Figure 2.2 Two point threshold for tactile stimuli

A ideal tactile display should have 500mN/mm² peak pressure, 4mm per stroke, 50Hz bandwidth and an actuator density of one per mm². (Moy et.al, 2000). This ideal device is ideal for human skin on the finger. Since we have different properties on different parts of our skin, we assume that the specifications for a ideal tactile device differs depending on where on the body it its placed.

2.2.5.2 Multimodality

When argumenting for a multimodal approach to designing wearable computers we employ a strategy which takes advantage of our human capability to code and understand information that is presented to different modalities. Humans can process information from two or more modalities, such as visual and auditory, and understand that the information regards the same phenomenon in the real world. It comes natural to us that the person we see moving her lips is the same person whose voice we hear in our ears.

A key goal of a theory within a multimodal approach and theory is to develop understanding of unimodal and multimodal representations for the purpose of supporting the design of effective interaction between users and their, often, computer based systems. These representations would be a set of mapping rules between the real world and each modality.

A multimodal approach takes advantage of the properties and attributes each modality inhibits. During interpersonal dialogue, people routinely and flexibly select the modality in which they can avoid errors and maximize their counterparts understanding. In parallel their multimodal production is very powerful due to the different channels can provide complementary advantages in different situations. During multimodal communication, a user's multisensory perception can achieve a remarkable accuracy by using a fusion of different information sources. (Oviatt et al, 2004).

Without the possibility of using the nuances given with a natural multimodality in communication, as in the case of E-mailing or talking on the telephone, we tend to develop strategies to recover the missing nuances. One way of adding the nonverbal information in for example an E-mail is the use of Smileys.

Recently, empirical research has stated that a multimodal input seldom co-occur temporally in interaction between humans or human –human computers. (Oviatt et al, 2003). Physical input such as sign language or written language were typically delivered earlier then spoken input. The users dominant multimodal integration pattern was during the research very consistent and resistant to change, even when strong reinforcement in order to switch input pattern was made, from a sequential to simultaneous or vice versa.

To gain user acceptance for a multimodal system, the response times must be reasonably small, preferably less than a second. (Flippo et al, 2003). The robustness of a multimodal interface increases notably as the number and heterogeneity of modalities expand. Performance improves even more when adaptive processes changes the interface to better fit each users context and environmental characteristics (Oviatt et al. 2004)

2.3 Task environment

There are several models that can be used when describing the environment of a human being. The one used here was developed by Driskell and Salas (1991) (figure 2.3) and models a soldiers cognitive chain between perceiving a phenomenon and resulting in an action. Further on the word agent will refer to a dismounted soldier working in a real world environment. The model is based on a traditional normative and rational decision model that has it's limitations in understanding the strategies which an agent uses when making decisions in a complex context. Although we believe that it can be seen as a basic model for the processes which generally occurs during a decision cycle.

2.3.1 Agents (soldier) task

Soldiers uses many cognitive skills in order to make good decisions. The working context is harsh and hostile which in turn demands a lot from the soldier and their ability to make decisions that will be victorious. In order to fully understand the context of a soldier the mental representations and cognitive environment needs to be analyzed. The following model is a generalization of such an environment.

Knowledge Base

An agent present a memory consisting of their competence. They have different skills in, for example, tactics, experience of similar tasks, and problem solving strategies. This knowledge base is at centre for the possibility to succeed in a mission. The knowledge base is also shared within a group and cannot be found in a particular agents mind bur observed during action (Plous, 1993).

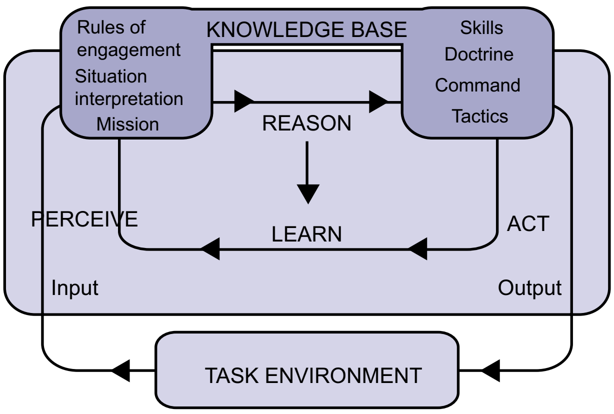


Figure 2.3 Working environment

Perceive

When input is gathered through our senses, generally vision and hearing, and then decoded using experience and other cognitive mechanisms the agent get an early understanding of the situation.

Reason

When a situation is perceived, the agent needs to consciously reason about what is perceived and what is required to be done. This is made in order to formulate a decision, e.g. to solve a problem in the world, as a foundation to perform an act. In a world where there is an abundance of information, our cognitive system risks getting overloaded.

A common theory on human memory argues that it consists mainly of two parts; the long term memory (LTM) and the Short Term Memory (STM) or working memory (Baddeley, 1998). According to Baddeley, our perceptual system is divided within our working memory that, in itself, is limited in the amount of data it can store, 7 ±2 digits. (Eysenck, 1993). The digits represent meaningful units, which are arbitrary in its size (Roediger & Goff, 1998). One unit doesn't need to consist of only one letter or number, but of a meaningful whole such as a concrete picture, a word or a phenomenon that have a meaning to us.

Our senses share an arbitrary amount of cognitive space (Van der Heijden, 1999. Eysenck, 1993). In order to process the incoming data in our consciousness the data has to be processed in our working memory. This means, simplified, that when overloading this memory storage it need to vent itself to make room for the new data, a cognitive overload (Eysenck, 1993, Plous 1993). Cognitive overload creates a loss of data in STM (Baddeley, 1998) and it can also cause stress and fatigue (Schneider, 1993). The reasoning is not always logical and complete, and often humans uses strategies that have been working in similar situations in order to minimize the cognitive load (Plous, 1993).

Learn

When reasoning, we tend to learn through mental simulation of acts and performing acts in the real world (Rips, 1994). When simulating, the agent can create different anticipated outcomes by using stored knowledge. This can be seen easily when comparing experts with novices. Experts possess and combine a greater experience as well as larger amount of stored knowledge and understanding than novices about a certain phenomenon. An agent has a Knowledge Base consisting of memories from earlier situations, from training or live action. The concept of learning consists of many competing theories and it is important to understand that we only cover a basic understanding of learning.

Act

The act comes into play when an agent has made a decision. The act makes changes in the Task environment and the process of perceiving takes another turn.

2.4 Hostile environments

Environmental factors are of uttermost importance when it comes to military applications. The word environment isn't here only a denotation of the nature or the soldier's surroundings, but also the cognitive representations that helps the agent to understand the task environment.

Decisions, acts, and planning are always made in teams, since a soldier never works alone. It is crucial that every designer who tries to design a wearable artefact for this extreme user group keeps in mind that the teamwork needs to be augmented or at least not restrained by any design decisions. When confronted with a situation in the task environment, agents gets input through perceptive abilities such as sight, smell, hearing and tactile channels.

Plous (1993) argues that the decision is biased in such a way that humans try not to make computation, but rather retrieve information from their experience and stored knowledge (knowledge base). This is done to relieve our cognitive workload and to speed up the time decision takes to be made. When a decision is made, we act. This presents changes in our task environment and an assessment has to be done in order to confirm that the anticipated outcome has occurred. We need to do this all the time and it takes time. Not a very long time but there is significant evidences (Plous, 1993. Yates & Estin, 1999) that more data at one time increases time to make a correct decision.

The task environment that soldiers work in is extreme and puts great demands on the material that is to be used. Not only do different weather conditions present a problem, but also how soldiers operate. Central in their work is to succeed in their mission and survive it, preferably unharmed. In order to accomplish these fundamental goals they need information and competence. The everyday training in different scenarios gives the soldiers the competence and confidence so that they can be ready whenever similar situations occur in real life.

As Driskell & Salas (1991) state, military combat environments are some of the most hostile arenas in which humans must operate. In many ways, this working environment is unique, with servicemen operating at the limits of their cognitive and physical ability, endurance and stamina, and with acute life/death consequences. As a result many stressors may impact upon the soldier and in detailing the effects of stress in the military operational environment.

When designing wearable computers this needs to be taken into account. For a soldier, two of the perceptive abilities present primary input channels for environmental information, mainly the visual and auditory. When input, which is continuously perceived throughout time, has been perceived a soldier reason about the situation and tries to make a decision on how to act. For certain situations instinctive acts can be made, but we believe that many of them have been learned and reasoned over when it was a novice situation to the agent in question.

3 Methodology for development

Designing a wearable artefact for a very complex environment as the military, under a limited time frame and budget puts great demands on both methodology and user understanding. This calls for a combination of several methods. The extreme nature of a soldier's context makes a user centered design framework very applicable as it not only focuses on the users present context, but also acknowledges the context after an introduction of an artefact.

A user centered design framework is quite free, as it is in itself a combination of methods to elicit as much information about a user and her context. In the following chapter possible methods for design, the retrieval of contextual information and communication between developers and users are discussed.

When designing a wearable artefact, the context of use and users are central to the artefact's adoptability to the domain of use (Preece et al, 1994). User needs are often hard to elicit since much of the working knowledge is tacit (a part of the memory that cannot be verbalized, such as how to ride a bike), thus difficult to communicate to a developer. To overcome this problem a range of methods has been developed, such as several context analysis methods and methods for user studies. When using these methods there are several factors that has to be addressed and appreciated, like social, physical, psychological and interactional contexts. Each factor can be assessed with a variety of methods.

A context is not always easy to systemize as it often is complex and constantly changing. The documentation regarding activities is often extensive, which demands time and effort to understand and analyze (Oulasvirta et. al., 2003). Another factor is the time that is available for investigation and analysis, thus creating limitations on how useful or adaptable these methods can be.

3.1 Knowing the context

Within the contextual design methods (Beyer et al 1998), all work is based in the designer's understanding of the potential user situation and his work tasks. To gain knowledge all tests, observation or other operations are conducted in the user's context (workplace, home environment, etc.), with focus upon environment, task, situation, social, interactional and other related things that impact the user during activity. Since the collected data will be a foundation to the design and thus have a great impact to the end product, it is very important to decide at an early stage what data that will be needed and how it is going to be collected.

In a collaborative situation, where individuals act in teams, several different competencies are to be found. Collaborative organizations are highly complex, consisting of multiple interacting factors, as the people in the organization are each having different roles, expectations and motivation for their work. The technology used today, and the technology to come, has different functions and reliability. Looking at the structure of the organization and of the work, the different partitions within the groups, and the culture of history, rituals, habits, ways of behaving, codes of practice and ways of talking, all have a fundamental role in the overall organization. Designing an artefact depends on the knowledge and interests of this group of individuals. Adding new technology to an existing organization does change its context and may also add a shifting approach to power and politics, which in turn is not trivial to elicit or predict in beforehand

Designing a tool for a dynamic and complex organization, are even more demanding than the inherent complexity, since the users and designers find themselves as part of ever-changing environments. To gain knowledge of the group and the individual members that it consists of, contextual inquiry can be used. Preece et al (1994) denotes contextual inquiry as an approach to ethnographic studies used for design where the designer works as an apprentice to the user. Beyer and Holtzblatt (1998) on the other hand describes contextual inquiry as a tool to enabling understanding of the users, their needs, desires and their approach to their activities on a day-to-day basis, to reveal the hidden structures. The most typical format for contextual inquiry is, according to Preece et al (1994), a contextual interview, which is a combination of observation, discussion and reconstruction of past events.

The contextual inquiry interview differs from ethnographical in a number of ways

- It is much shorter than ethnographic studies. A contextual inquiry lasts about 2-3 hours in contrast to the ethnographic studies which stretch out for several weeks or months. Often this method is called Quick and Dirty Ethnographic study.
- The interview is more intense and focused, while ethnographical studies takes in a wide view of the environment
- In the interview, the designer is no longer a participant observer but an inquirer of behaviour and of the work.

One contextual method that has been used within the field of Ubiquitous Computing is body storming. Wearable computers not only introduce a new artefact into a user context, but also have physical properties which need to be analysed early in the design process. Wearable computers have an attribute, by default, to be pervasive and embedded into the natural habitat of the user; clothing, accessories or similar. Many methods within HCI haven't considered physical properties which is a problem in developing a wearable artefact. Oulasvirta et. al. (2003) describes a method that has been used to elicit physical properties of a certain context and how a ubiquitous computer artefact be invoked. There are other methods that concerns physical properties such as Role Playing (Jones, 1992), user-centred ergonomics scenarios (Preece et al, 1994) and similar methods.

One method which we find interesting because the scientists themselves are involved in the research and scenario is Bodystorming (Oulasvirta et. al., 2003). Oulasvirta et. al. describes Bodystorming as "Brainstorming in the wild". Further he argues that the method can introduce new creative ideas to a design by putting the designer in the centre of use and not only as an observer. An understanding of the studied phenomena increases when having hands-on experience with the context.

3.2 Communication tools

When developing a wearable computer we believe that it is a necessity to test a prototype with some functionality in a natural environment in order to find out as much as possible about the possible problems that a new artefact presents when introduced into an environment. Prototyping is therefore necessary but not sufficient for a user centered development. According to Andersen (1994) prototyping is a methodology in which a prototype, a test version, of a planned product is created before put in full scale mass production. The prototype gives the development team an opportunity to test and communicate the product in its potential market as well as its appearance, functionality and technical implementation.

Within the field of system development the methodology is primarily used as a means to ensure that the final product fulfils the customers' expectations and needs. The process of prototyping can be more or less iterative, one or several prototypes may be created during the development process, but at least 1 iteration is assumed.

Andersen (1994) means that there are two different forms of prototyping, one devoted purely to technical development, whereas the other is based upon an interface- and functionality development. The technical form can for example be to develop and test a product's performance or distributive properties, i.e. concurrent using, update algorithms or real time demands. In this form of prototyping, the product does not need a full functionality or a user interface that is actually possible to use for the end customer. User interface and functionality prototyping on the other hand, should be designed so that the user is given an as realistic interface and functionality environment as possible. Here the technical functionality is not needed to a full extent, sometimes it lacks entirely and the test personnel have to imagine it all together.

Preece et al (1994) takes the interface and functionality prototyping even further and characterizes three different types of prototypes, full prototypes, horizontal prototypes and vertical prototypes. Full prototypes have a complete functionality and user interfaces, but lacks in performance (i.e. Andersen's interface and functionality prototype). The horizontal prototype shows the full user interface and lacks both functionality and performance where the vertical prototype shows only a part of the system, with a complete interface and functionality.

These prototypes can come in different varieties that Preece et. al. (1994) denotes as:

- High fidelity prototypes that use a prototype that is close to the final product, e.g. having an HTML-dummy showing the possible functionalities of a website or a database.

- Low fidelity prototyping using cheap materials to quickly make a mock up-prototype e.g. having sketches or cardboard models of the product.

- Chauffeured prototyping involving a user that watches while a designer "drives" through" the system at its present state, explaining how it will work.

- Wizard of oz-prototyping having a person acting out the behaviour of the computer.

Tightly woven into the design of an artefact within a user centered development is a constant evaluation of the design steps.

3.3 Analyzing the design

The purpose of user studies in HCI and Interaction Design is to find out exactly what the customer or client requires from the system (Preece et al, 1994), and they can, and should be, conducted all through the design process. Depending on when user studies are performed, the result differ; if it is done in beforehand to require information and background knowledge, during the development process to evaluate and gain feedback to design proposals, or afterwards for evaluation and to see if the goals have been achieved.

For every phase there are different methods. A main distinction regards using qualitative or quantitative methods to elicit data. Quantitative methods gives an opportunity to measure and statistically analyse gathered data. A limitation to these methods is that they can have a low external validity, which means that a generalisation of results to the real world are hard to make (Shaughnessy and Zechmeister, 1997). Qualitative Methods gives more information that are applicable to the real world. This creates a higher external validity, but in return a lower internal validity. Qualitative methods also lifts the attitudes and thoughts that users have. Through these methods Interviews require a huge amount of preparation to set up questions and goals, and to fully understand the purpose of every question. The designer asks one individual or a small group of users their opinions, needs and wishes, and the users are not able to be anonymous. It is very important that the designer puts effort into creating a relaxed atmosphere, trying to make the user comfortable to establish a good contact. It is always difficult to make the user describe their problems with a system as they might think their problems with usage stems from their own perceived "stupidity" and not because of the systems poor design, or they might be frightened of criticizing their employer's choice. Another problem is that participants may feel that critique can give repercussions after an interview is concluded.

It is important for the interviewer not to ask leading questions, to beg for a particular answer based on the interviewers own expectations or personal attitude. There are two main types of interviews, structured and unstructured (Preece et. al., 1994). Structured interviews have predetermined questions, and the focus is not on individual differences and nuances, but the answers are more often used for statistic comparisons. Unstructured, or flexible, interviews are less formal and work very well in an early stage of the design process. The purpose is to investigate the user's individual attitude, and the interviewer is free to follow the user's replies in a new direction. Even though it is less important with predetermined questions, it is very important to set up goals for the purpose of the interview, to prevent completely losing the subject.

User observation is used to observe the user interacting with a system (Preece et. al., 1994). Depending on the purpose of the observation, the user could be asked to perform a specific task or to do their normal work. The result from any kind of user observation can be affected by the fact that they know they are being watched and might therefore become nervous and eager to do everything perfect and right, even though the effort is to see the user perform their work in an environment totally uninfluenced by the observer. The observations can be recorded by video to gain the most informative facts, by audio also known as a verbal protocol with spoken observations, or by notes that will be the most incomplete ones.

Using expert groups as a design method does have its advantages and disadvantages. This method uses a group of experts that are involved in the design process. Since the experts are specialists then there is a risk to loose the common user, but the method is perfect when designing for a small group of users (Preece et. al., 1994). It is a quite expensive method, but since the experts have extensive knowledge of the environment where the design is to be used and/or about the problems to be solved, then the development process could benefit greatly from this. The method is necessary when the context is unknown for the design team, but can be useful in any design process.

When it comes to user studies there are always different factors in the design of an artefact that will make different methods more suitable than others. Often a combination of studies is a good way to elicit as much relevant information as possible.

3.3.1 Laboratory based methods

One problem with functional prototypes is that they can have sensitive electronic equipment that prevents the use of natural settings. When such problems surface an analysis in a laboratory setting can be useful. Preece et. al. (1994) argues that laboratory experiments enables a high degree of control of the analysis but also lowers the external validity. This makes the experiment harder to generalize to the real world domain. Since a natural setting cannot be implemented when conducting a laboratory experiment researchers introduce manipulated conditions of the factors they want to study (Preece et. al, 1994). Ordinary experimental methods including a control group that isn't exposed to the manipulated condition, choosing this does in turn require a larger population to be tested in order to draw reliable conclusions from the sample. Pre-experimental designs are so named because they follow basic experimental steps but fail to include a control group. In other words, a single group is often studied but no comparison between equivalent non-treatment groups is made.

4 Adopted methods

In the light of the differences between quantitative and qualitative methods and due to the fact that the research made in this report focuses on comfort and usability of tactile data the use of methods that elicits attitudes and thoughts about a design have more impact on future work which renders a use of a qualitative framework in methodology.

In order to design PalpEye several factors and subjects need to be looked in, we initially chose a regular literature study to gain more information around the subjects that needed exploring. In the above mentioned methods some were more suitable to our project than others.

In a military context soldiers train every day using scenario techniques and a constant evaluation of their problems and behavior. This eases the use of contextual methods for eliciting information about the context and user needs. It does, however present difficulties when testing wearable computers in a natural setting. Wearables can quite easily be tested and evaluated in a physical environment while testing within the psychological environment is harder. We believe that soldiers, when in battle, experience a cognitive load that is very hard to test in a training situation.

4.1 Data gathering

The "user" of MARKUS-products is well defined and their potential tasks are very well recognized from an organizational point of view. Still, the authors felt that further analysis had to be made in order to fully understand the context of use and of the user needs.

In order to establish a solid knowledge of the users and their task environment we needed to analyze their context as well as the users in order to have a foundation to stand on for future development. The methods which were decided to be used were Bodystorming as well as observation and informal interviews in order to require as much information as possible.

Beside the fact that a lot of information and requirements about the user and the environment was already established, there remained factors to elicit, namely an understanding of the problem space. Therefore we saw a need for an analysis of the task environment, the soldiers work situations.

When it comes to the technical problem space a literature review was best suitable. Since PalpEye consists of different layers of technology, there was a need to get an understanding of recent developments in flexible display technology as well as tactor and textile materials.

Not only does the context present a methodological challenge to PalpEye, but also which prototyping method and evaluation method that is to be used.

4.2 Design process

When conducting the design of PalpEye we decided to create a prototype in order to test it in its real environment.

Data gathered during the Bodystorming and technological review resulted in a foundation for the prototype to be built. Early on in the project, we use low fidelity prototyping techniques as sketches and paper mock–ups to communicate our thoughts between each other and to external contacts.

The final prototype incorporated the concept of PalpEye which had some of the functionality and attributes that a final product would have. Standard COTS electronic material was used for the purpose of creating a fairly cheap and changeable construction, without the extensive time frame that specialized electronics or textiles would give us.

During the design, stages of testing were made in order to comprehend what properties function regarding the tactile interface. These informal testing stages were primarily conducted on ourselves.

4.3 Evaluation process

Since we adopted a user centered design framework an evaluation on the design were needed and we therefore conducted an user test.

PalpEye has got sensitive electronics which presented us with a problem. The military environment is too harsh and the weather conditions at the time for the test (February) included wet snow and possible rain. Unfortunately this prevented us from doing our test in a natural setting and context. Instead a laboratory test was conducted in order to find out about user attitudes as well as possible problems with the initial design.

Accompanied with the test of a high fidelity prototype a non functional mock up was created to be included in an outside treatment of the design. This included ordinary movements for the soldier in the snow wearing the mock up.

5 Technology survey

One of the goals of this thesis was to develop a functional prototype to, as realistically as possible, test our hypothesis on using tactile information in a military context. To gain some early knowledge and get some ideas of usable technology, we conducted a literature survey. The following chapter is a summary and evaluation of the technology we found present on the market today.

5.1 Textiles

Fibers from natural sources, twisted by hand into yarns and threads and then refined by some method into cloth, dates back over 10’000 years. Apart from hand tools, the technology had not changed much until the dawn of the industrial revolution in 1775. The available fibers such as cotton, wool, silk or fibers extracted from stems or leaves of plants or other hairs, remained virtually unchanged until 1875 when advances in chemistry led to an ability to construct new materials. (Hearle, 2001)

Nowadays, according to Hearle (2001) the textile market is satisfied by six chemical types of fibers:

- Cellulose, in cotton, other plant fibers, and rayon and its derivative cellulose acetate;
- Proteins in wool, hairs, and silk;
- Polyamides, mainly nylon 6 and 66;
- Polyesters, mainly polyethylene terephthalate (PET or 2GT);
- Polyacrylonitrile (PAN) acrylic fibers, and other vinyl polymers;
- Polyolefins, mainly polypropylene.

In addition, there are elastomeric fibers like polyurethanes, aramids (aromatic polyamides) and other polymers are used for special purposes, but does not have a large deal of world textile markets..

5.1.1 Characteristics of textile fibers

There are several ways of describing fiber sizes (Hearle, 2001). The most common is mass per unit length, i.e. linear density which can be described as:
The SI-unit tex, which is grams per kilometer, or the submultiple dtex, decitex
denier, grams per 9000 meters

For clothing and other household textiles the appropriate dimensions the textile fibers ranges from 1-20 dtex which gives fiber diameters of 5-50µm. Coarser fibres are known as monofilaments, ranges from 0,1-1mm. Microfibers down to 0,1 dtex (~3µm) have recently been introduced as well as nanofibers with ranges down to 3-300nm (Oppermann, 2001).

Table 5.1 shows typical properties of the more important textiles. Roughly the fibers can be divided into subgroups depending of their strength and extendability in a standard atmosphere, 65% relative humidity at 20°C. Note is to be taken that the natural fibers properties can vary due to variety and growth condition (Hearle, 2001).
The densities of textile fibers give them a considerable weight advantage over many other structural materials, which may give the use of textile a wider range as the fiber-technology proceeds.

Low strength, low extension

- Rock wools
- Rock wools
- Rock wools

High strength, low extension

- Aramide
- HMPE

Tough (due to combined strength and extension)

- Nylon
- Polyester
- Polypropylene

Less tough (lower combines strength and extension than above)

- Cotton
- Wool
- Rayon

Very high extension

- Lycra

	$(gcm)^{-3}$ Density	C^o Melting point	(%) Break extension
Cotton	1.52	~200 (chars)	6.8
Wool	1.30	130 (decomp)	43
Silk	1.34	175 (chars)	23
Viscoserayon	1.49	~200 (chars)	27
Acetate	1.32	250	24
Acrylic	1.19	200 (sticks)	25
Nylon 6/66	1.14	215/260	46/20
PET (Polyester)	1.39	260	37
Polypropylene	0.91	165	17
Para-aramid	1.44	500 (decomp)	4.4
HMPE	0.97	147	3.8

Table 5.1 Typical Properties of textiles

Natural, such as cellulose- and protein based fibers and to a lesser degree, nylon, absorb water to a measurable extent (Calvert, 2001). The absorbed water causes swelling and changes the property of the fiber. Adding chemicals to a fiber can give a textile special properties, for example, flame resistance, antimicrobial action and ultraviolet protection. Most textile fibers will stand temperatures up to 200°C, but at some higher temperature they melt, char, or chemically decompose in other ways.

5.1.2 Fiber production and textile

The major ways in which fibers are assembled into fabrics. In yarn making the natural fiber, with its non-infinity length, needs to be twisted, entangled or in other ways bonded together to give a yarn any strength. For a continuous fiber that is not necessary. Although to get a more natural fabric feel, the engineered fibers are cut into staple fiber length and often also blended with natural fibers before spun to yarn.

5.1.3 Fiber types

5.1.3.1 Natural fibers

The main structural material in plants, cellulose, is a condensation polymer formed of biosynthesis (Calvert, 2001).

5.1.3.2 Plant fibers

The cotton fiber is a single plant cell, the seed hair of the genus Gossypium. Plant modification through breeding and genetic engineering has led to a great amount of different species and traits. Cotton fiber dimensions range from short, coarse fibers to long fine fibers, approximately 1,5cm, 3dtex to 5cm, 1dtex. Most fibers in a crop are although in the size of 2,5cm long and 2dtex. Cotton and other plant fibers are quite unusual in its property that it is stronger wet than dry, due to relieves of internal stress.

Wood provides the most common plant fiber all categories, as it is also is the raw material to regenerated cellulose fiber. However, the wood fiber is generally too short for textile production. The main textile plant fiber is extracted from stems or stiff leaves, from species as flax, true hemp, sisal, jute, pineapple and ramie, a member of the nettle family. These fibers were once of great importance but have been outmaneuvered by cotton and manufactures fibers in textile production (Hearle, 2001).

5.1.3.3 Wool

Wool is more resilient and durable than cotton, but some of its properties have been replicated in synthetic fibers, and it is now more competing on quality and tradition than actual property advantages. Wool has been used as a raw material to textiles for ages, and as such been the subject to several man-imposed changes such as breeding sheep on wool quality rather than ability to endure climate. The wool fiber is therefore different depending on what sheep race the fiber is originated from. Slightly elliptical, the fibers mean diameter ranges between 15-50μm and length between 100-150mm, fully grown.

Each wool fiber has small scales on the surface, which, together with other structural features determines the specific properties. The scales cause the fibers to entangle into felted mats, which is seen as a defect as it causes shrinkage, but can also be used to make fabric. A feature of wool which is quite unusual to yielding materials is that it recovers completely from 30% or less extension. In a dry state the recovery is often incomplete, but wetting the fabric completes the recovery fully. This feature is an important factor in the durability and appearance retention of wool fabrics

Other hairs used in textiles are those of goats, such as cashmere and mohair, more are the Angora rabbit, vicuna, alpaca and camel. Depending on species the fibers have other properties and characteristics which give particular features to the fabric and also add to the cost of the resulting textile (Hearle, 2001).

5.1.3.4 Silk

In contrast to other natural fibers the silk is not formed as living cells, but are extrusions of protein solutions which coagulate in the air when drying. The silk moth larvae extrude the silk when forming the cocoon in which it metamorphoses into a butterfly. Each cocoon yields about 700 meters of usable filament. Silk has the highest work of rupture and a good recovery, which makes it the toughest of all natural textile fibers.

5.1.4 Man-made fibers,

5.1.4.1 Cellulose derivatives

The cellulose derivatives have a natural base component in wood, but as stated before, the wood fiber in itself is inadequate as a textile fiber. However, several different techniques have evolved to extract the filaments, such as etherification and esterification.

Viscose is an example of a cellulose derivative, made by reacting cellulose with sodium hydroxide and carbon disulfide. The filaments are extruded though an acid bath after filtering and aging, and stretched to increase strength and reduce uncontrolled extensibility (Hon, 2001).

5.1.5 Synthetic fibers

5.1.5.1 Melt spun synthetic fibers

Nylons and PET polymers are characterized by repetitive section that contains flexible, inert section alternating with more interactive sections and have a melting point between 215-260°C. Molten polymers is extruded, cooled, solidified and stretched to get orientation. With the development of partially orientated yarn, where the molten thread-line is rapidly wound up before solidification the production of comparatively low-strength, high-extension yarn, suitable for direct use in fabrics (Wilson, 2001).

At around 100°C the stiff regions in the fiber loosen up and the structure opens up to enable dyeing. This temperature also gives an opportunity to temporary heat-set the fabric. To permanently set a shape into a fabric a temperature between 180-240°C is needed. At this temperature the fibers start to stick together. Setting processes are used in the production of textured yarns and to fix creases or otherwise stabilize fabrics. In nylon, it is necessary to go to more severe conditions to overcome a prior treatment, but PET can be reset at any temperature in the range.

As the techniques have developed, the PET has become cheaper and cheaper to produce. With the addition of it’s versatility in use purposes; PET has come to be the largest manufactured fiber in the industry. PET can come in many shapes and textures, from the soft behavior and feel of microfiber textile to cheap, nonwoven disposable surgeons’ gown or braided replacements to human ligaments. (Hearle, 2001).

5.1.5.2 Solution spun synthetic fibers

The major uses of polyacrylonitrile (Acrylic or PAN) are bulky and warm fabrics as an alternative to wool. Yielding at only 2% extension the acrylic yarn is much weaker than nylon and has poor recovery from higher extensions. Fibers which have been highly stretched or broken show a high shrinkage when heated.

Modacrylic fibers contain less PAN and more copolymer groups, but properties are generally similar to acrylic fibers. The copolymer gives the fabric special properties such as flame resistance, high performance and specialty synthetic fibers (Manocha, 2001).

Para-aramide fibers

The aramide fiber Kevlar, polyphenylene terephthalamide (PPTA), was the fist successful HM-HT polymer fiber. Kevlar cannot be melted but experience a chemical degradation in temperatures of 500°C. Other heat treatment under tension increase or decrease modulus to meet application needs. Kevlar suffer from a low compressive strength, although it gives the fabric an advantage as it is not brittle when bent. The PPTA fiber is comparatively strong, but it will break after a few thousands cycles, due to flexural fatigue (Hearle, 2001).

High modulus polyethylene

HMPE-fibers are made by gel spinning of polyethylene with extremely high molecular weight. The strength and modulus are higher than for aramides but has a very low melting point since properties wear off when temperature rises above 40°C. The fiber finds its application in ballistic protection and industrial fabrics as well as in some composites (Hearle, 2001).

Thermally Resistant Fibers

The meta-aramid fiber Nomex, can be spun into fibers with mechanical properties comparable to general textile fibers. The advantages of Nomex are excellent thermal stability, flame resistance, and good dielectric properties (Hearle, 2001).

Elastomeric Fibers

Elastic threads can be made from natural or synthetic rubbers, but it is not possible to make good, fine fibers. Spandex fibers, such as Lycra, are made from segmented polyurethanes from the reaction of a di-isocyanate with polyethers or polyesters. Amorphous soft segments give the elastic extension, and crystalline hard segments cross-link the structure and hold it together. The fibers are relatively weak, though the true stress at break is high, and have elastic extensions over 400%. They are resistant to physical and chemical damage in use, and are incorporated in fabrics when high stretch is required (Hearle, 2001).

5.2 Tactile actuators

When approaching the use of tactile interfaces, there are different techniques which can induce the feeling of touch on the skin. These tactile actuators, tactors, all need to deform the skin by some extent to induce a sensation of pressure, vibrations or pain. As PalpEye is supposed to work in a worst possible environment, we have decided to constrain this chapter to a few usable techniques.

Stimuli based on pain, heat or cold have been regarded as unwanted stimuli as the subject's reaction is individual and thus hard to control (Kron & Schmidt, 2003). Another reason is due to the fact that the device will be used in a diverse environment and that a subjective determination of the stimuli can be hard to interpret when receding in these environments, such as heat or cold. PalpEye is a military artefact and soldiers task environment is, simply stated, the worst possible. Therefore technology that creates these stimuli is not regarded in the following analysis. Pain is also a stimulus that is very subjective in what degree that stimuli are regarded as pain.

Tactile displays have been designed before, but often as haptic Braille displays (Fricke, 1997) in order to create a small device to produce symbols and Braille signs for blind individuals. These displays are mainly made for human fingers, which have more sensitive receptors than the parts of the body which is suitable for PalpEye.

The use of vibrotactile stimuli has been a dominating tactor technology when creating a tactile display that isn't connected to the fingers in any way. Gemperle et. al. (2001) created a harness with vibrators connected to it and then placed on the upper body.

Notably is that all research here mentioned have been conducted with placement on the hand or fingers. Within the vibrotactile area, there has been research on several micro-electro-mechanical systems (MEMS)- techniques to produce tactile displays. These techniques have all positive results regarding the users cognitive ability to determine the type of pattern or representation for different tactile stimuli. Piezoelectric (Caldwell et. al., 1996) elements have been used in order to incorporate some tactile stimuli. Others have tried to use Shape Memory Alloys (SMA) (Howe, 1994) or electrostatic technologies to create tactile stimuli (Jungman & Schlaak, 2001)..

The development and research on tactile displays have been slow, due to the mechanical requirements of many tactors (Moy et. al, 2000). The human skin has a receptor frequency where a tactile stimulus is sensed, 50 – 600Hz (Toney et. al. 2002, Moy et. al., 2000). For a tactor to be suitable, movements within these frequencies are required. Besides the frequency, the ideal device for realistic tactile feedback on the fingers are a 500mN/mm² peak pressure, 4mm per stroke, 50Hz bandwidth and an actuator density of one per mm² (Moy et.al, 2000). Further Perez et. al. (1990) showed that the maximum sensitivity to the abdomen was 250 Hz. Note that Moy et. al. (2000) created these requirements for human skin on the finger. Since humans have different properties on different parts of our skin (Shiffman, 1994), we assume that the specifications for an ideal tactile device differ depending on where on the body it's placed.

All technologies present positive as well as negative aspects in their ability to produce tactile stimuli. To narrow down what characterize the different tactor technologies there is a need to elicit fundamental properties of each technology and weigh it against the purpose and use of PalpEye. Besides the stimuli given, different technologies have attributes regarding size, power consumption and endurance, among others.

Besides stimuli, technologies have been disregarded because of technical limitations. Pneumatic tactors are such a technology. It can create pressure stimuli, but the need of many components and its sensitivity to distance from the skin as well as the low frequency (Jungmann & Schlaak, 2001) makes it hard to embed into a garment and simultaneously produce reliable stimulus. However, it can still be useful as a tactor in other applications. PalpEye will be used in many situations that include movement such as; climbing, crawling, running and many other kinds. Therefore we believe that the tactors move over the skin in a variety of ways which can create problems in perceiving the stimulus.

Below comes a limited survey of different existing technologies to create tactors usable for applications such as PalpEye. Technologies that are excluded here can therefore be used for other applications.

5.2.1 Shape Memory Alloys (SMA)

Shape Memory Alloys use a change in their material properties, the Shape Memory Effect (SME) that transform some metal alloys when being subject to temperatures above or below a specific "transition temperature" (figure 5.2) (Robertson & Busch, 1996). The transformation can involve changes in the material's strength, deformability, Young's Modulus , as well as the ability of the material to return to a previously trained physical shape. The shape change effects are generally much greater and occur over a much smaller temperature range than those of thermal expansion or contraction. The typical SMA are a combination of metals such as nickel and titanium (NiTi, or "Nitinol") or copper, zinc and aluminum (CuZnAl). When the materials conduct electricity, change in temperature can be internally generated by resistance heating, or induced by an external heat source.

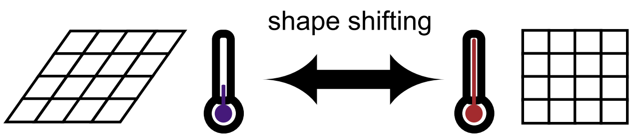


Figure 5.2: SMA effect (Gilbertson & Busch, 1996)

There are in general no direct and simple relations between the temperature and the position or force. Therefore, accurate position or force control by SMA actuators requires the use of powerful controllers and the experimental determination of complex data. Many mathematical models are being developed nowadays by different research groups to overcome this important limitation

According to Stalmans and Van Humbeeck (1995) applications based on SMA technology cannot be designed in the usual way. One reason is that the mechanical and physical properties change to a large extent during transformation, so that single property values cannot be used.

Zheng et.al. (2004) found that a nickel-titanium SMA had stable properties, so one can guess that the technical difficulties will be overcome eventually. Another reason for the difficulties of designing with SMA is that is that shape memory alloys, different from structural materials, are used because of functional properties and, can be substantially modified by alloy composition, etc... Therefore, the design of shape memory applications requires either (i) a thorough knowledge of shape memory behavior, (ii) a close co-operation with an SMA supplier, or (iii) the use of specific computer programs which might evolve to expert systems (Stalmans & Van Humbeeck, 1995).

Advantages

These materials exert high forces at large displacements. SMA materials can create small tactors and small effects. This is a promising technology for the future.

Drawbacks

Due to the thermal capacity of the material causing heat up and cool down times, the actuation frequency of SMA-actuators doesn't exceed 10 Hz. This low frequency is to low to create reliable tactile stimuli (Moy et. al., 2000). In order to increase transition times a cooling system needs to be implemented, which creates a larger device. Because of the high thermal loss resulting in a temperature increase close to the human skin, special precautions must be taken to prevent injury. It needs high voltage to create the SMA effect which is a drawback in mobile applications. SMA uses heat as deformation actuator which also presents a problem. Some materials have a low transistion temperature (body temperature) where other materials have a high temperature that is harmful to human skin.

5.2.2 Piezoelectric

Piezoelectric motion arises from the dimensional changes generated in certain crystalline materials when subjected to an electric field or to an electric charge (figure 5.3) (Robertson, Busch, 1996). Structures can be built which gather and focus the force of the dimensional changes, and harness them to create motion Typical piezoelectric materials include quartz ($SiO2$), lead zirconate titanate (PZT), lithium niobate, and other polymers.

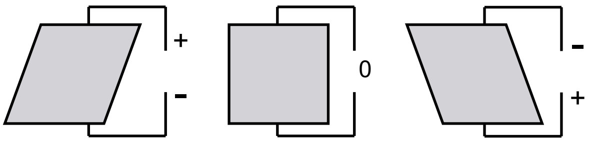


Figure 5.3: Piezoelectric effect (Gilbertson & Busch, 1996)

Piezoelectric materials respond very quickly to changes in voltages and with great repeatability. They can be used to generate precise motions with repeatable oscillations, as in quartz timing crystals used in many electronic devices. Piezo-materials can also act as sensors, converting tension or compression strains to voltages (Caldwell et. al., 1996).

Advantages

Piezo-materials show high forces at a wide frequency range. Many piezo- materials have been used successfully as tactors for Braille displays (Fricke, 1997) and is a fairly simple technique to master. A main problem of those actuators is the low strain of approx. 0.2%. To ensure high absolute elongations, lever mechanisms are used that result in large construction height at the desired actuator density.

Piezomaterials are space saving depending on technique. However, using a Bi-morph, as in Braille displays, can become bulky. The drive circuitry to piezo materials are most space demanding. If placed external, away from the piezo material then size is reduced.

Drawbacks

Piezo materials are sensitive to moisture and therefore needs to be encapsulated and protected from outer factors. Besides this, Caldwell et. al. (1996) created a sensor from a piezoelectric disc which had to be charged with 160-300V which can be harmful for the human skin.

5.2.3 Electromagnetic

Electromagnetism arises from electric current moving through a conducting material (figure 5.4). Attractive or repulsive forces are generated adjacent to the conductor and proportional to the current flow. Structures can be built which gather and focus electromagnetic forces, and harnesses them to create motion. Typical examples of electromagnetic devices include electric motors, solenoids, relays, speaker coils, and cathode ray tubes. Electromagnetic fields arise and disappear rapidly, thus permitting devices with very fast operation speeds. Since electromagnetic fields can exist over a wide range of temperatures, performance is primarily limited by the properties of the materials used in constructing the actuator.

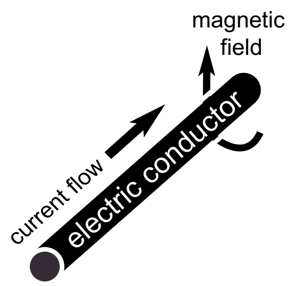


Figure 5.4: Electromagnetic

a) Electromagnetic Solenoid
Solenoids are used as actuator elements to transform rotational or linear movement. Solenoid actuators of the desired dimensions reach their physical limit in respect of the exerted forces. Solenoids are, used as tactors and especially in Braille displays. Advantages and drawbacks?

b) Electromagnetic vibrator
An electromagnetic vibrator is a small motor with a center displaced weight on the motor axis which creates vibrations when rotating. This technology have limitations regarding size and stimulus level. Their size, depending on technology (pancake or standard), differs a lot, pancake motors have a diameter of >10mm, thickness ranges from 3mm to 6mm. When regarding standard size motors they have a diameter of >3mm and a length of >12. Pancake motors are encapsulated, which creates a motor without visible moving parts. Standard motors have a weight that needs to be encapsulated before using it as a tactor, since it can get entangled into clothing or hair.

Advantages
Wide frequency range which can enable multiple layers of tactile stimuli. Frequency, pulses etc. Have been successfully used as tactors in a variety of studies (Toney et. al., 2002, Gemperle et al, 2001).

Drawbacks
Limitations in size creates large display height regarding solenoids, tactile stimuli regarding stimulated receptors.

5.2.4 Electrostatic

Electrostatic charge arises from a build up or deficit of free electrons in a material (figure 5.5). The free electrons can exert an attractive force on oppositely charged objects, or a repulsive force on similarly charged objects. Structures can be built which harness the electrostatic force to create motion. A common example is Van de Graaf generators produce large electrostatic charges that literally make hair stand on end. Rubbing an inflated balloon or walking across a carpet on a dry day can develop a small but noticeable charge. As with the electromagnetic fields, electrostatic fields also arise and disappear rapidly. Such devices will likewise demonstrate very fast operation speeds, and be little affected by ambient temperatures.

Advantages
Small devices, fast response time and a wide frequency range.

Drawbacks
High voltages close to the skin can be harmful and therefore needs to be capsulated. Electrostatic tactors use the charge of the skin to lift against the tactor. This presents a sense of feeling. Drawbacks to this are the skins sensitivity to electrical charges and the substrate that is needed to protect the skin from the electrostatic field. (Jungmann & Schlaak, 2001).

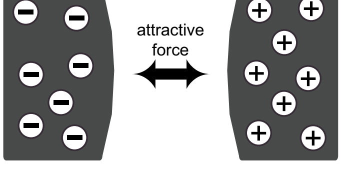


Figure 5.5: Electrostatic effect

5.2.5 MEMS

The development of spacecraft technology has historically resulted in an abundance of commercial spin-offs. The medical, automotive, robotics, and instrumentation markets have stimulated great advances in the field of micro-electro-mechanical systems (MEMS). Commercial MEMS products today include chemical sensors, acceleration and pressure transducers, and micro valves. In fact, many of these devices are so small that they are best observed with the aid of a microscope.

MEMS technology can also incorporate more than one technology in one and the same tactor, so as to create a wider spectrum of tactile stimuli. Tang and Beebe (2003) created a electrotactile display for the roof of the mouth using MEMS that stimulated pain receptors by applying a small electrical charge to the stimulus area.

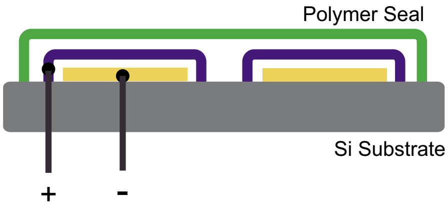


Figure 5.6: MEMS Principle

Advantages
Small devices with a large diversity in implementable technologies.

Drawbacks
MEMS are a new technology that has problems to deal with before usable in tactile display applications.

5.3 Bendable Visual Displays

A bendable display would adjust its form to the physiology of the soldier and it would be both easier and thinner than a traditional display. Besides this fact a military application needs low power consumption in order to fulfil the demands that have been put on electronic equipment (72 h of operation between reloading). There are different technologies in which to manufacture a bendable, or even foldable, display and the following review will only consider two of the main techniques that engage researchers around the world.

5.3.1 Organic Light Emitting Diods (OLED)

Organic light-emitting diode (OLED) displays, also known as organic electroluminescent (OEL) displays, have been used in creating displays for wrist watches and present a competing technology since they can been viewed in direct sunlight and have better viewing angles than most traditional LCD displays (Raghunath & Narayanaswami, 2002).

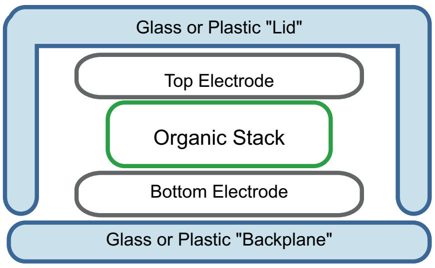


Figure 5.7: OLED Principle

In traditional LCD's are two sheets of polarizing material that sandwich a liquid-crystal solutionused. When an electric current passes through the solution, crystals align to block out part of the backlighting and form the desired image (Raghunath & Narayanaswami, 2002). OLED displays, on the other hand, emit light themselves. An OLED display is comprised of a layer of organic light-emitting polymers placed between a cathode and an anode (figure 5.7).

Applying a voltage across the cathode and anode causes the organic material to glow (Raghunath & Narayanaswami, 2002). The structure of the polymers used affects the light-output frequency, which determines the colours of the emitted light. The amount of current applied determines the light's brightness.

OLED displays deliver brighter images and, by eliminating the need for backlighting, use less power and offer a thinner form factor than LCDs. Lower power usage is important in lap tops and handheld devices, which run on batteries. When regarding power consumption of an OLED display it is proportional to the amount of pixels turned on. Consumption also can be regulated with the contrast and brightness levels. Besides these factors OLED displays are lighter (no backlight needed) and have a faster response time (Mansikkamäki, 2003).

OLED's are more sensitive to moisture and oxygen than LCD and OLED displays therefore have been sandwiched between layers of glass in order to seal out moisture (Mansikkamäki, 2003). The result is a good moisture barrier but it impedes the flexibility and reliability that is needed for wearable computer artefacts.

5.3.2 Electrophoretic Displays

Electronic ink is a material developed by E-ink Corporation. The ink is made up by small, electrically charged, capsules. The particles within the capsules are charged positive or negative depending of colour, negative if black and positive if white. To enabling the distribution over a surface, the capsules are diluted in a colourless, clear liquid.

When a positive electric field is applied to the solution, the black particles are moved to the top of the capsule and thus create a black field. The white particles are subsequently drawn to the capsules bottom and hidden (figure 5.8). To create a display the ink is printed on a substrate which doubles as a circuit board. The substrate creates a pixel-like pattern of capsules which can be controlled by a computer. Because of the fact that the capsules are diluted in a liquid, the manufacturers claim that the material the substrate is made of, is of a lesser importance and therefore enables displays to be built in any material, polymers, glass, textile or even paper. Two characteristics of E-ink which enables the production of thin flexible displays is that the location of individual pixels is defined by the addressing electrodes and that the electrode gap is not important which is the case in OLED's.

E-ink display effects are relatively thick (about 50 micron) and the liquid with electrostatic particles is encapsulated in polymers to form a coherent film. Since E-inks display effect is rather slow, video feeds cannot be shown with a good result, but the option for flexibility give it a reasonable chance for replacing paper. It's switching speed and the fact that its display effect does not allow multiplexing (The combining of two or more information channels onto a common transmission medium), that causes E-ink displays to require an active matrix backplane.

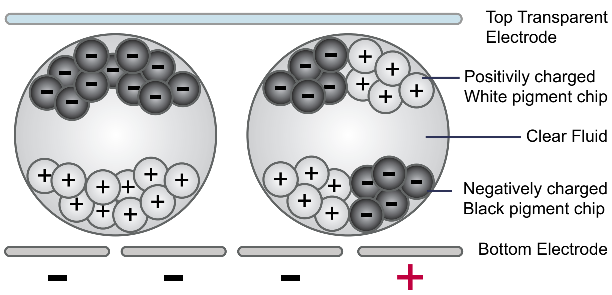


Figure 5.8: E-ink Principle

Substrates on which to embed technologies
Most flat panel displays consists of four layers. The first is a backing substrate (backplane) that provides mechanical stability. Secondly a layer of switching electronics that rides on the substrate follows and makes each pixel addressable. Then there is a light controlling layer and a front panel that carries the top electrodes, encapsulates the light-control material and offers strength.

Traditionally the backplane is made of glass but several attempts have been made using different plastic substrates. The problem with plastics is partly that ordinary lithographic patterning techniques cannot be used, and that it is technically demanding to maintain the electrode gap as the display is flexed to different curvatures. Plastic substrates are also permeable to moisture and oxygen which in turn destroys the OLEDs (Mansikkamäki, 2003).

A thin flexible display can reduce weight and thickness by 50 to 90%, P.J. Slikkerveer (personal contact, nov 2003). It is thought to create a more diverse way to implement visual displays in wearable computers.
In order to make displays bendable the substrate on which the different display technologies is applied must have bendable properties. Traditionally displays have been made on a glass substrate that besides being fairly thick also are brittle and not bendable. Research have been made using different kinds of polymer materials to make displays bendable.

Advantages of plastic substrates compared to glass
Polymer materials are lighter compared to glass. The use of plastic substrate can significantly reduce the weight (1/3 of glass substrate) and thickness (less than 50% of glass substrate). Polymers are not brittle and plastic displays are resilient (10 times more than glass substrate) with higher impact resistance and durability to glass counterparts (Mansikkamäki, 2003).

Disadvantages of plastic substrates compared to glass
The mechanical properties of glass to withstand temperature required for some manufacturing steps are better than polymer substrates. The application of precise photo-lithographic process to substrates that might even slightly change their shape during production is problematic. The permeation barrier for oxygen and water molecules for polymer is worse compared to glass.

A traditional display made of glass have spacers dispersed in them and a vacuum holds the rigid glass down on the spacers. With plastics, you get a flexible unit where substrates are not rigid and fluid can move around inside. Non-rigidness of substrates causes a problem in maintaining a uniform cell gap between the two substrates.

In a flexible LCD the glass substrate is replaced by a polymer substrate. This enables the flexibility of the display, so that besides the conventional flat positioning of displays their curved arrangement becomes possible. In addition, the use of polymer substrates leads to a reduction in weight and to an increased fracture resistance, which is particularly important for applications in mobile products, e.g. for applications in mobile telecommunications.

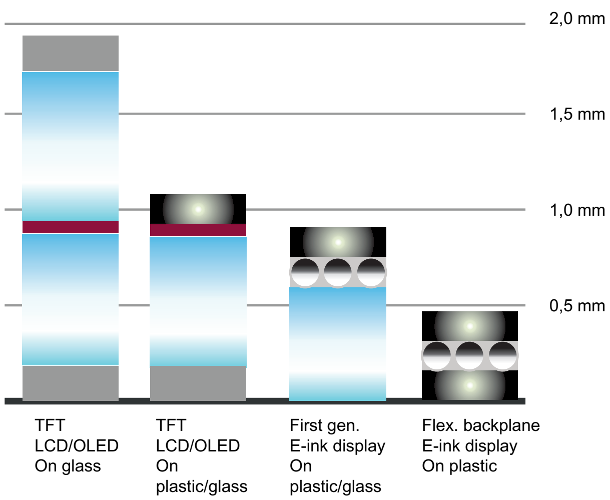


Figure 5.9: A Comparison of common display technologies [1].

	Glass	Polymer	Glass & Polymer
Thermal & Chemical Stability	+	−	+
Mechanical Stability	−	+	+
Water & Oxygen Permeaton	+	−	+
Flexibility	−	+	+
Weight	−	+	+
Special Manufacturing processes	+	−	+

Table 5.10: Compared properties of display substrates

6 Developing PalpEye

The development of PalpEye consisted of three intertwined phases; context analysis, prototyping and evaluation. The context analysis consisted of a literature review as well as a session of Bodystorming, with an addition of regular observation and short, informal interviews with the potential user population. The data which were collected during this session was used in order to create the final prototype which in turned was used as a tool to conduct the final usability test.

There is some problems regarding the validity between civil and (Driskell & Salas, 1991) military research. This has not been unnoticed, and we have tried to get a good understanding of the environment and the factors that the soldiers are susceptible to.

6.1 User and contextual analysis

Our first contact with the users was made during a visit at Kvarn in October. We decided to use a combination of methods and gain as much information as possible such as conduct observations, informal interviews and a session of bodystorming. The observations were made in conjunction with the session of bodystorming to comprise the time available for doing the context analysis.

An ordinary training situation for the soldiers consists of physically performing a certain scenario followed by a session of evaluation. This created a situation where we could interfere as little as possible and still get a hold of much information about their context and problem they saw. As the training session contained several repetitions of the same events, although the role and position of the soldier participating did change, we had good opportunity to observe and follow the role and position shifting and what problem each soldier was a subject to.

The interview took place during natural breaks and shifts in training conditions. This gave us a lot of thoughts from the soldiers as the information was up to date and present to their memory.

6.1.1 Bodystorming

With us we also had a make –shift prototype to show our thoughts to the people at Kvarn, and to test our idea in a more practical form. The Bodystorming as well as the observation was made during a day when soldiers were training on military tactics in their natural environment and context. We also joined the exercises wearing combat clothing including ballistic protection (helmet and vest), uniform and combat harness. Weapons were not included due to security reasons.

During the session of Bodystorming we concentrated on some of the factors we found earlier during observing the users performing their tasks. With the use of our low fidelity prototype we concentrated on the movement and the context of use so as to get an idea of the problem domain.

The most prominent problem we found during our observing session was the one of giving and receiving the correct order when in an environment that compromised both visual and auditory contact attempts due to for example weapons noise, smoke, undulating terrain and/or wind direction

We also saw the diversity of the group. The groups consisted of 6-8 persons, and they differed not only in roles but also in weaponry, and above all, in their personal stature. It made us very aware of the need of being able to adapt PalpEye to the wide varieties of human sizes.

6.2 Requirements

Among the problem the observation gave, was that new problems arose when the soldiers changed environment. Tactics that was trained to work in one condition raised new problems when natural conditions changed (hills, trees, water). Other factors that surfaced was the problem of communication. When firing a gun it is hard to hear what is being said and soldiers often commented on the problems that it made them not respond correctly to changes in strategy or tactics. Combining vocal order giving with visual symbols to enhance communication gives a limited effect, due to the fact that soldiers need eye contact to retrieve orders. The need for visual or vocal cues gives the soldiers a limited working range.

By doing a project concerning the Swedish Armed Forces and their equipment, we had first and foremost to consider their underlying requirements, to which all Swedish military equipment are measured and judged. (Basic system demands from Swedish Armed Forces, [2])

In short, the overall requirements on a soldiers gear are:

- Functional
- Flexible
- Climate comfort
    - d. Heat insulation
    - e. Moisture transportation
    - f. Layer upon layer

- Protection
    - h. Flame protection before second degree burns
    - i. Flame resistance
    - j. Shrapnel
    - k. Wind, weather
    - l. Chemical warfare
- Movement comfort
    - n. Flexible size system
    - o. Material choices

These requirements are general and very extensive, not all of them applicable on PalpEye. We thereby ranked the requirements by a scale of importance.
We categorized the demands of heat insulation, shrapnel and chemical protection and wind and weather protection less important since PalpEye are to be used inside the uniform. The primary protection demands will the soldier's uniform take care of, but the requirements are however important to consider in the design work so that the final design does not exclude any of them by inherent design choices.

With a base in the above stated demands we created a demand specification of our own, where technical and functionality demands were added. Some requirements may show up several times, this does just mean that it is important in several aspects:

Textile requirements:

- Must be comfortable to wear for a long period of time
- Should never feel wet (non absorbent although transmit sweat)
- Wear and tare –proof
- Lightweight
- Should not worsen an acquired injury by its properties, such as melting or catching fire under 200°C
- Should not become brittle or show any other structural deterioration above -40ºC
- Enable to pass the unchanged vibration onto the arm.

Functionality requirements

- Enable to pass the unchanged vibration onto the arm.
- Any material should be appropriate to integrate electronics in and/or between two layers
- Function in extreme temperatures
- Full functionality must be retained within the temperature range of -40ºC -+70ºC

Technical requirements:

- As few components as possible (reduces sources of errors)
- Must be able to be run on battery power at least 72 hours
- Small component to reduce size
- Instant reactions, no heating up or cooling down-time should be needed
- Cordless input if possible

6.3 Designing PalpEye

6.3.1 Placement

When we started pondering about exactly where to place the tactors on the body, we evaluated different placements, such as on the shoulder, around the neck, back arm, or on the legs. To ensure that every symbol was interpreted correctly, it was important to find some placement on the body where PalpEye came to fit close to the body without moving around too much or being uncomfortable.

Placing PalpEye around the neck, we judged could get uncomfortable in for example warm weather. The sensitivity to having something on the neck is also very individual, some persons would promptly refuse wearing anything tightly-fitting on their necks and thereby would disqualified the use of PalpEye completely.

Since soldiers carry most of their equipment on their shoulders, we needed to ensure an even surface between the carried load and the body. Therefore a PalpEye placement on the shoulders was judged as unsuitable, as the electronics would make it quite far from smooth.

The placement of PalpEye on the back became rejected on the same premises as the shoulder and neck placement. Remaining options were the legs or the arms. As stated before, we wanted PalpEye to be easy to access information from when necessary. When feeling a movement on the skin, a natural reaction is to glance in the direction of the sensation, while PalpEye consists of two parts, one “invisible” with the tactors, and one visible, we wanted to take advantage of this natural instinct.

Having a display on the leg is a little unpractical and also hard to conceal in darkness, or other covert situations. Placing only the motion part on the leg and the display on the arm for example, would need a bit more training since the instinct to look where the movement came from would have to be repressed. Even though that idea would be practicable, as training is an everyday thing to a soldier, replacing a natural instinct with a learnt reaction instead of working with it would take an unnecessary amount of time and energy in training. It would also demand more of the soldier at a cognitive level.

More natural is the placement on the arm, the soldier already has his arms in front of him when carrying his weapon. The lower arm is relatively free of equipment as it is and easy to check with a glance. Secondary, the electronics would be more protected on the inside of the arm and the two parts of PalpEye would be easier to connect together as the distances grow small.

6.3.2 Form

When the project started, we had not really a clear thought of how an artefact such as PalpEye would look like. The only thought we had was to create some sort of tactile stimuli on the skin, together with a visual display to augment and/or interpret the signals and eventually create some sort of symbol language to communicate information.

Early on in the project, we used low fidelity prototyping –techniques as sketches and paper mock–ups to communicate our thoughts between each other and to external contacts. The prototypes have also served as a memory when writing this report.

The following chapter will present each prototype incrementation by itself, discussing thoughts and inspiration that preceded the development, followed by a description of the prototype. Since the product that, at last, became PalpEye: version 1, still is just a prototype made of standard electronics and textiles, we have added a conclusive part where the "ideal" choices of electronics and textiles are discussed.

6.3.2.1 Iteration 1 – Start up

The first prototype was inspired by an article in the newspaper Ny Teknik 030910 [2]. The article concerned a small company that used shape memory alloys (SMA) to make a pressure dressing to prevent bleeding in an extremity. Their invention stemmed from research on G-force suits for air force pilots.

The idea of tactile stimuli had occurred in the first informal conversations, but this article came to be the stepping stone for our development work. Why not use the same technique but using the SMA's movement as the symbol language? During the following discussion, the idea of combining tactors with a SMA-"ribbon", for example, around an arm, and thus extend the set of symbols possible, increasing the amount information communicable.

As seen on figure 6.1, the first thought was to place a quite large amount of tactors and/or sensors on a broad, snugly fitting, closed structure on the forearm resembling a brace. We recognized early on that the brace needed to be comfortable for it to be used and therefore thought of some sort of tricot or netting as base material. The tricot/netting should provide the soft comfort, as well as transporting moisture away from the body and creating a layer between the metal in the vibrator to prevent nickel-allergy or heat rashes.

Since our thought of tricot and netting were that it easily sagged and was too flexible to retain the tactors for a longer period of time, we needed something to give a firmer, yet

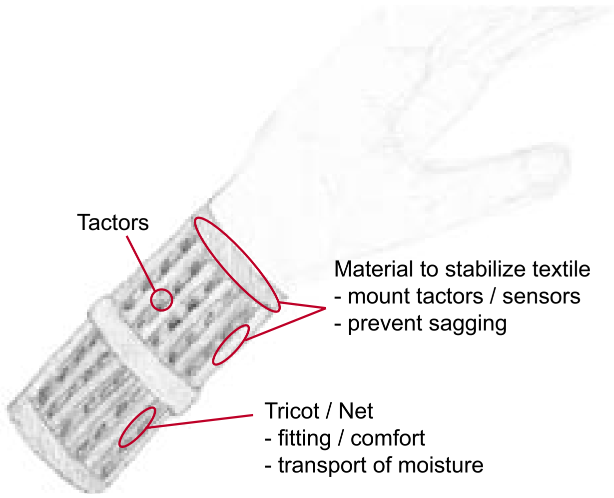


Figure 6.1: Eearly paper based prototype.

flexible structure, still soft enough to be comfortable. A sort of trimming was added as a framework, stabilizing the brace and serving as a place to securely fasten the tactors.

By placing PalpEye on the forearm, we quickly realized that we had added an extra dimension of difficulty, namely that of movement. Any person that has tried to wear stay-ups or dress-gloves with some sort of dignity, recognize this problem. The forearms conical shape, with the narrowest part in the "bottom" together with gravity, makes it difficult to actually fasten something on the arm and make it sustain its position for a longer period of time. Apart from the conical shape, the elbow joint creates a twisting motion on the forearm, which adds to the tendency of clothing slipping down to the wrist. The solution was to add a silicone string closest to the body, just as a stay-up stocking works like.

6.3.2.2 Iteration 2

In the second iteration the first realized prototype was made, a quick and dirty one, made from a wrist protection glove and a picture taped on top a flexible, plastic square with Velcro glued on the sides (fig. 6.1). Elastic band formed two loops that enabled the picture to be worn on the arm. Adding elastic band to the picture instead of using a closed structure, made it easier to adapt to a greater variety of arm sizes.

Also the wrist protection glove was adaptable by five sets of velcro connectors. Since a closed structure demands making a collection of several sizes, we found that opening up the thought brace and adding velcro and/or some elastic band would enable us to create a standard piece that would fit any person.

6.3.2.3 Iteration 3

With the third revolution we went back to the drawing board. The brace was now opened up, and we added the vibrators. There are several kinds of vibrators on the market, we chose the smallest and most protected as we could find, a pancake vibrating motor, 12mm in diameter and 3,4 mm thick (appendix A). Choosing this kind of motor gave us a problem of how to embed them on the textile since they are

Figure 6.2: low fidelity prototype, Wrist protection and a picture.

completely smooth, except for a small tongue with soldering contacts.
We solved the problem by making tight pockets between two layers of fabric and using the soldering tongue as a stopper. Another problem was the sheer size of the vibrators. As Shiffman states; to distinguish between two separate points of contact on the forearm, the points needed a distance of at least 11mm between each other Using the space of one of the authors forearms as a template, we tried to fit in as many vibrators as possible into that space.

The two-point threshold together with the limited amount of space on a forearm drastically reduced the amount of tactors possible to integrate into PalpEye. In this stage we decided to limit the amount of tactors even more and also to revise the idea of have tactors placed evenly distributed over the whole of PalpEye. The reasons for revising placements of and reducing the amount of tactors were mainly two-folded, one technical and one of function and comfort.

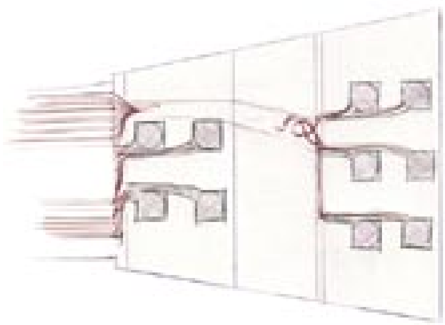


Figure 6.3: Trapezoid Sketch

Using the space of the inside of the smallest authors' forearms as a template, we tried to fit in as many vibrators as possible into that space, with at least 11mm in between each tactor. The measurements were 9cm closes to the elbow joint and 5cm at the wrist. We then added some extra centimeters on the outside to have something to fasten the velcro on.
By separating the tactors into two fields we ensured that, at least these two sections were to be felt separately, if the tactors would not.

A trapezoid shape mimicked the shape of the forearm and as though the tactor fields are separated, they are still hanging together through the fabric, which is in one piece (figure 6.3). The cords would run in a canal sewn into the two layers of fabric. The canal was thought to reduce the risk of entanglement and protect the cords itself from too much movement, which also ensured that the tactors did not shift position. By dividing the cords into two separate canals we wanted to make the connection between the display and the tactile part as thin and flexible as possible.

6.3.2.4 Iteration 4

At iteration 4, we were quite satisfied with the design on paper. However, when the time came to realize the paper design into a textile product, we had to revise our thoughts yet again.

Using a stretchy fabric as a base layer, it proved hard to cut and sew a trapezoid form that would keep its shape also after a few tugs and stretches. It tended to loose form quite quickly. Another factor was that it got hard to fit in the vibrators after sewing the shape. The two middle rows of vibrators had no entrance opening to insert them into the fabric. An alternative was to place the vibrators between the two layers of fabrics and then sew them into the arm piece. We turned that idea down as we considered it hard enough to get the shape right without having to steer bits of metal in between. The vibrators would also be in the way of any standard sewing machines, and therefore require hand sewing. Not a good property if PalpEye were to be produced in a larger scale.

So, rethinking again, we decided to alter the shape from a single trapezoid form into two separate rectangular shapes, connected with a tube, in which the cords would run. By changing the single form into two, we gave the middle row of vibrators an entrance, and, which was a positive surprise, improved the flexibility of the arm as well as an increased stability of the positioning of PalpEye on the arm. Having only a single tube as a connection, the two rectangles were able to move more independent of each other. It also became much easier to add some more "slide-prevention" to PalpEye

The actual area to fasten the vibrators did not change compared with the trapezoid; we just used the largest part in each vibrator section and stretched the sides to form a rectangular. The shadowed fields are where velcro connectors should be fastened.

6.3.2.5 Iteration 5

After sewing up a few Iteration 4-versions in different materials (pictures in the Material choice-chapter), we wanted to try out if we could minimize the size without losing any functionality. There was an unused space between vibrators and the velcro; what would happen if we removed it? By putting the velcro as close as possible to the vibrators we managed to reduce the wrist-part by a total of 4cm and the arm-part 6cm. Reducing the width may potentially be an advantage as very small people could wear it without having the ends meet on the top of the arm. Minimizing the material will eventually reduce material cost when in production. It may also become more comfortable to wear since a small thing is easier to forget then a large, but in writing moment we have not tested it.

6.3.3 Textile

6.3.3.1 Choice of textiles

After contacting some textile– and sewing companies and the textile department at FMV, we got quite a few samples on different textile material. All textiles satisfied one or more of the criteria we had set up at the beginning of the project. The problem now was to sort out what textiles that satisfied all our criteria, if possible. The textiles evaluated range from a filmy, gauzy silk to a sturdy polyamide weave, used in military backpacks. Some textiles were of a natural origin, such as silk and cotton; others were synthetic or a combination of them both.

At first it was a bit tempting to use only natural textiles such as cotton or silk, because of their nice properties when heated; silk or cotton does not melt on the body, it just chars. Other properties such as softness, ease of purchase and environmental aspects; it does not require oil or other irreplaceable resources, also spoke for the use of natural textiles. Unfortunately, other, more critical requirements, such as moisture transmission and durability were not satisfied by the natural textiles, and therefore they were discarded.

Synthetic yarns have, as stated in the background chapter, very different properties depending on what material it is made from. We had four, equally important, requirements that were the focal point in the selection of a synthetic textile, namely fire control (melting point and inclination to catch fire), transmission control (moisture and vibration), thermal comfort and flexibility.

With the requirement of melting (flame protection), we, after a consultation with Anna Söderholm at FMV, decided to only consider textiles that had it's melting point above 200°C. If the temperature at PalpEye's location rises above 200°C, it is reasonable to believe that it is caused when the outer, insulating layers of the uniform is faltering. At 200°C, the skin already has required a third degree burn, and is therefore dead, no further damage will make any real difference.

As a base layer, our first try was a black polyamide warp tricot, used in undergarments, which we got from Anna Söderholm. The textile was very thin and stretchy, which provided us with the flexibility and sleekness we needed to make PalpEye comfortable on the skin. It also had excellent transmission properties, both for vibrations and moisture. The melting point was above 200°C, it was not prone to create an open flame, and as such acceptable in every requirement stated. We have not tested its durability to truly rugged condition due to time shortage, but it will be a requirement if PalpEye should be further developed

Hitting bull's eye with the under layer textile at first try, we got slightly over confident and thought the rest would be a fairly simple. How wrong we were. The upper layer and composition of PalpEye came to be an entirely different matter. The same requirements as stated above were valid also for the upper textile, with some minor adjustments. The requirement of unaltered vibration transmission was now less important, since it's not needed to transmit vibrations to the skin.

To not risk the functionality of PalpEye, for example, in the aspect of two-point threshold, we needed to ensure that the form stayed the same over time and regardless of movement. Therefore, to the upper layer, we needed a textile that were soft, flexible and would retain its structural integrity over a long period of time.

We also made a different interpretation of the flexibility requirement, as the upper layer should bear the structural integrity of PalpEye. We still wanted it to be flexible in the meaning of soft and bendable, but it should preferably not be stretchy. A stretchy material is difficult to handle, because of its softness and flexibility it has a tendency to fold up and loose form. It also tends to loose its recoverability over time, which is a disadvantage.

From Claes Nideborn at SACCI, Borlänge, we got several samples of green textiles that had its every day use in combat vests and bags. Most of the textiles were too heavy or non permeable to fit as an upper layer, but we found two mesh fabrics, one weaved with a slightly thicker yarn than the other, that seemed very appropriate. The meshes were used in combat vests and made of a polyester, weaved so that would not create ladders when damaged. The meshes were flexible enough to be comfortable but still stiff enough to not crease or loose form. By using a mesh with relatively large holes, a lower hole frequency, the moisture transmission and thermal comfort were secured, and as a standard material of a combat vest, we confided in that the military had tested the textile well enough to ensure the fire properties. The thinner version of the meshes became our number one choice for a long time, mainly for its thinness, in all other properties they were each others equals.

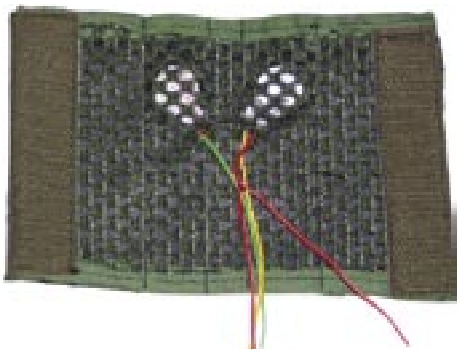
The final choice, however, came, once again, from Anna Söderholm at FMV. Which was a mesh, similar to the one from SACCI. The mesh was a prototype weave from the development of the current combat vest and had similar properties to the SACCI-meshes. It was much softer and had a higher hole frequency in comparison to the SACCI-meshes although still retaining its structure as the former fabrics, and it was black, which provided PalpEye with a nicer look.

6.3.3.2 Textile composition

The first trials were conducted with materials that we knew would not meet the stated requirements, but as some of our “special” textiles were more of a finite resource than others, we did some trial and error to get a feel of the sewing process. Question that arose was such as: What techniques to use? Would we need trimmings or not? In what order should the seams be added? Would the design be feasible to sew at all? Having slightly limited experience of sewing techniques, many trials were needed before a presentable idea emerged. The following example pictures are added in chronological order and commentary added below picture.

1. Very early trial version

2. Front side, nice looking but uncomfortable



3. Front side, ugly looking but comfortable, vibrators added

4. Backside, anti-slide trimming added

5. Early version put together, no trimmings what so ever, just some velcro

6. Iteration 5-version ready

We found that the velcro and the top and bottom trimmings stabilized the structure enough to consider a softer material. We therefore tried the prototype material from Anna and found it not only to work just as good as the SACCI-mesh, but also too look much better. Last we sent the two final versions (appendix B) to a professional seamstress, MonAmie in Borås, to somehow get a professional look on our PalpEye. Another reason for getting it professionally sewn was to increase the ability to withstand rugged conditions.

6.3.4 Electronics, code and input device

Electronics and input device

To control the vibrators on the arm we used a BasicX chip (BX24) with two Darlington drivers. The drivers were used since the BX24 couldn't produce enough power to run all ten vibrators at the same time. As a display we wanted to use the E-ink technology, but it is still at prototype stage and much too expensive for us (50 – 100 000 SEK a piece), so we had to limit our testing to only test the idea with visual queues together with the vibrators.

We used a serial LCD 2x16 display (figure 6.4) to give the visual queues. The display was mounted inside a textile brace with several layers of polystyrene foam around it to prevent damages.

Figure 6.4: LCD-implemented prototype

For the test, we needed some sort of input device. We decided to limit the functionality of PalpEye version 1 to only use and transmit four commands; Fire (Eld), Cease fire (Eld upphör), Forward (Framåt), and Take cover (Skydd). These commands are short, distinct and often used. To transmit the commands to PalpEye we decided to use a remote control of some kind. At first we had in mind to use radio to transmit the orders, but due to technical difficulties and time shortages we resorted to using a chord between PalpEye and the "remote". By using a chord we needed only one BX24 chip to run both PalpEye and the display.

We placed the electronic box (appendix C) in one of the combat vests many pockets and threaded the chord through the side of the vest, over the shoulder and left enough leeway to ensure unlimited movement of the arm. For a complete list of used electronics, please refer to appendix A.

Coding

The code that we used for this version is very simple (appendix D), basically a loop that waits for one of four buttons to be pressed. Each button represents a given order and when a certain button is pressed the corresponding vibrators are run. The symbol of each order is a combination of inactive and active vibrators denoted as follows:

- **Forward!**
  - The “end” rows of tactors, the one closest to the elbow and the wrist are run as a short pulse in sequence, creating an oscillating motion.
- **Fire!**
  - A short pulse on the upper row of the arm.
- **Cease Fire!**
  - a single long pulse where all vibrators are run simultaneously.
- **Take Cover!**
  - Short pulses in a right-to left motion repeated once on the wrist.

LCD
When a button was pressed, the correspondent order was given and a describing text was shown on the display The LCD was configured from manufacturer to be run by a Basic Stamp-chip, not the BX24 we used. The difference caused some problems when writing the control code, since each chip requires a different protocol when programming it. It was however solvable in the end.

6.4 Testing PalpEye version 1

Testing of symbol language
We continuously tested the prototypes during the development phase. The testing resulted in design changes described above and a change in how some orders were communicated.

Each order consists of a combination of short or long pulses that sometimes were repeated. At the first trials with the full functional PalpEye a short pulse continued for 0.5 second, and a long pulse for 1 second. We realized that the frequency and force of the vibrations together with the sheer size of the vibrators made the long pulse very annoying, especially when all vibrators were run at the same time.

Therefore we reduced the time for a long pulse to 0.5 seconds and the short pulse became as short as possible, approximately 0.25 seconds. We have no exact timing on the short pulse since it is dependent on the processing time in the BX24. The BX24 is a sequential processor that requires a certain amount of time depending on the amount of coding it has to run through.

Testing the symbols for clearliness, we found that they were sufficient to form a crude symbol language, except for the Forward-command, which needed a change. In the beginning the Forward-command was thought to be a caterpillar-like motion over the whole of the arm, starting in the vibrator row nearest the elbow. After testing this we found that, even though we used as short pulses as possible, one command took too long time to run through, and the message was perceived and understood before the actual command ended. We found that after the symbol was perceived, any extra movement was considered unnecessary and somewhat irritating. We thereby changed the command to only running the “end”-rows twice and got a more distinct command to work with.

Context testing
In the beginning of March we once again went to Kvarn, this time to conduct a test of PalpEye in its proper surroundings. With us we had two prototypes, one functioning and one mock-up version (picture 6.5). The reason for using two different versions was that the electronics would, at this point, not be able to withstand a quite soggy, snow melting day in the woods without acquiring some permanent damages and thus make any further testing impossible.

The working prototype consisted of one combat vest with a chord running between the electronics and batteries in a back pocket, the display and the tactile part.

The mock up version had tactors within it, as well as some chords, to mimic the weight and feel of PalpEye with electronics. However, there was no chord connecting the mock up to combat vest since they used their own combat vest. As a display, we used a mockup version of a thin bendable sheet fastened on a textile brace.

Picture 6.5:Mock-up for physical test

Test subjects
As test subjects we had a total of 11 individuals, 6 soldiers with 7,5 months serving time, and 5 senior officers with serving time ranging from 26 months to 20 years. All subjects belonged to Markstridsskolan, Kvarn.

At the time of the test the soldiers and two of the officers had full combat equipment [3] on, which consisted of:

- Shirt M/90
- Sweater M/90 (optional)
- Field jacket M/90
- Field trouser M/90
- Marching boot M/90
- Socks
- Fragmentation vest
- Combat vest 2000
- Gloves
- Helmet
- Weapon AK5

The other three officers were in uniform, but had not fragmentation vests or helmets on, the sweater were optional for all.

Test planning
We planned the test as a three-folded test, one functionality test in a laboratory environment, one bodystorming with the mock-up version and a post test survey (appendix E).

The purpose of the laboratory test was to find out how the soldiers would react to the tactile stimulus, if the symbols used were distinct and learnable and to find out if the tactile interface were usable together with the other equipment a soldier uses.

Complementary to the laboratory test, the bodystorming session was conducted in order to discover any physical limitations or other problems of use in its proper context. The concluding post test survey was then added to evaluate questions regarding attitude, comfort, values of the stimuli given as well as to give possibility of a reflection over usage.

Test environment
The laboratory test was set up in a classroom, with a chair and a video camera as the only props. Each test was conducted with only two persons in the room at one time, the test leader and the subject. The subjects had their own equipment except from the combat vest, as they used our prepared combat vest instead.

The bodystorming was conducted outside, in PalpEye's proper environment. The subjects had the mock-up strapped on them and were told to act and react as they normally would in a combat situation. The mock-up was filled with vibrators and chords to gain the weight and feel of a PalpEye with function.

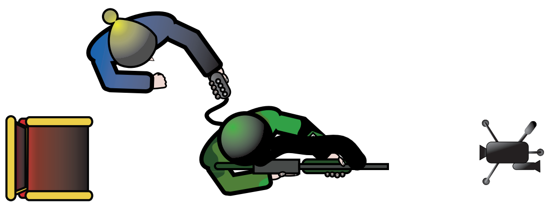


Figure 6.6: Lab - setup

The post test survey was conducted in a neighboring classroom which had an ordinary setting of benches and chairs.

Conducting the test
After a briefing about the test and its purpose, we divided the group into two parts by lottery. Each subject got a number or letter which followed them throughout the test. The number/letter was used as an identification mark to enable us to depersonalize the test results in the analysis. The group with uneven numbers started with performing the laboratory test, and the others started with the bodystorming.

In the laboratory test, each subject was exposed to the different symbols at a total of 20 times, 4 times as a trial time outside the test, 8 times with the aid of the display and 8 times without the display. The subject was asked to repeat loudly every order he got and also to act it out with some restriction, to somewhat mimic the response he would normally give in proper context.

The test procedure was as follows: A test subject had PalpEye strapped on and was placed facing a video camera with a chair and the test leader behind him (figure 6.6). As a soft starter, the subject was presented with the four different tactile stimuli and their corresponding representations on the display.

In the first part of the test, the subject was allowed to use the display as an additional cue of which order that was given. Each order was given in a predetermined order. Between the orders given, the subject was given some time to think and react. In the second part, the subject was not allowed to use the display to get a visual queue, in all other parts it was conducted exactly the same.

The bodystorming session was conducted outside, in a partially snow covered wooden area. The subject got the mock-up version strapped on and was sent to act out movements and weapon handling such as running, firing positions as well as shelter positions. Low positions including lying, crawling and sitting were also a part of the test. As the weigh is the same as in the full functional version, it vouches for a good authenticity of the test.

The post test survey included 15 questions regarding comfort, attitude and values of the stimuli given, which was based on a test made by Bodine and Gemperle (2003). The survey also included 4 open questions where the user had the opportunity to reflect on use.

Figure 6.7: PalpEye last prototype.

7 Results

7.1 Material used in prototype

Using COTS-electronics, the possibility to develop for an extreme environment became more or less impossible, since the technology in most cases is too sensitive to survive rugged conditions.

The textiles used were a black polyamide warp tricot, used in undergarments as it had excellent transmission properties, both for vibrations and moisture. The melting point was above 200°C, it was not prone to create an open flame, and as such fully acceptable. As an outer layer a black, soft, polyamide mesh was used to enhance the structure of PalpEye. The trimmings are a standard nylon trimming. To get as good fitting as possible, we used a stretchy variant of velcro as a connector. The display casing is made of a waxed nylon textile with a polyester ribbon and a standard snap-lock used in rucksacks (figure 6.7).

Tactile data is a one bit stream of data (Toney, 2000) and we believe that complex structures or graphics will be hard to represent with a tactile stimuli. In order to complement the tactile information, a visual display was implemented to enhance and enrich the information which is coded in the tactile pattern. As a display a serial, LCD 2x16 display with a BPK LCD driver board was used. The display was mounted inside the above described textile case with several layers of polystyrene foam around it to prevent damages.

Ten standard pancake vibrators were used to create the vibrating symbols on the arm. The vibrators were soldered to chords and placed in the pre-sewn pockets of the two-pieced brace. To control it all a BasicX24-chip was used together with two Darlington drivers as the BX24-chip didn't provide enough power to run all vibrators and the display at one time.

7.2 User test results

With the conducted test we wanted to evaluate the following questions:

- How would the soldiers react to using a tactile stimulus to communicate information in their context?
- Was the tactile interface usable together with the uniform and other equipment?
- Were there any physical limitations or other problems of use in its proper context?
- Were the symbols used distinct?
- Were the symbols used learnable?
- How was the soldiers' attitude towards PalpEye?
- How comfortable was PalpEye?

7.2.1 Laboratory test

In the laboratory environment, the test results ranged from 0% -100% correct reactions. A correct reaction is here a physical movement and/or a vocal response to the stimulus given. The part in which the subjects were allowed to look at the display, all subject had 100% correct reactions, and these results are not further discussed in this section. Without display aid, the results became quite different.

2 subjects had 0% expected reactions

1	12,5%
1	37,5%
1	50%
1	62,5%
2	75%
2	100%

The average result are (2*0+12,5+37,5+50+62,5+2*75+2*100)/10= 51,25% correct reactions.

The table (7.1) describes the non-visual aided test in numerical values. Each order was given a total of 20 times, but the amount of order perceived ranged from 16-21 times per order. For example, the order "Forward" was only correctly interpreted 9 times, whereas it was interpreted as "Take cover" 7 times.

7.2.2 Test survey

The survey was made out of 18 statements which the subject had to take a standpoint to and four open questions where the subject could reason and give comments about PalpEye and it's potential use.

		Confounded with				
Order given	correct	Forward	Fire	Cease fire	Take cover	total
Forward	**9**	x	1	3	7	20
Fire	**12**	4	x	3	2	21
Cease Fire	**12**	4	2	x	3	21
Take Cover	**8**	2	4	2	x	16
		Order percieved				

Table 7.1:Test result, condition without display

Tactile perception of PalpEye

The questions regarding the perception of the vibrations were generally very good, all subject stated that they felt the vibrations and that it caught their attention. However, the perceived distinguishability and mapping between order and perceived symbol were somewhat mixed. Approximately half of the subjects, 54%, found the symbols as clear, the other half found them partially unclear or unclear. On the other hand, the display was perceived as a good tool to understand the order given through the tactile channel by all subjects.

PalpEye's individual vibrators were considered distinguishable by the majority of our subjects, 73%. All subjects think that vibrations such as PalpEye's could be a help to get their attention at order giving.

Comfort of PalpEye

None of the subjects felt PalpEye as painful or unpleasant to wear, although 15% felt it as slightly uncomfortable. Generally, no subjects felt that PalpEye made them change their movement nor did it create a hindrance to their movements, or was perceived the vibrations as unpleasant or disturbing.

Open questions
The open questions gave many comments about the use of tactile communication and PalpEye in the subjects' context.

To the question about using the tactile perception as a source of communication, the general answer was that it seemed as a good idea, and it was perceived as a quick way of getting information while relieving the eyes and ears. However, the main opinion was that it primarily should be used in combination with the current ways of communication and not as a single source of communication. Another common opinion was that it requires some training before the signals are learnt and becomes natural in their communication.

As the soldiers are used to think in scenarios, we asked them when they thought an artefact like PalpEye could be an advantage or become a hindrance. Two scenarios dominated the answers; when advancing in a forest, buildings or other sites where sight or vocal commands are diminished and when an absolute silence is needed although the need for communication is retained. One subject thought that all soldiers could use one; both mounted and dismounted soldiers.

PalpEye was thought as a possible hindrance in situations of physical and psychic strain, where the vibrations may not be perceived as the soldiers' concentration is elsewhere. In the physical world, PalpEye's chords were thought to possibly become a hazard. PalpEye could also become a hindrance when extra equipment is carried. During the bodystorming we found that the weapon strap partially covered the display.

Concerning the wearing and comfort of PalpEye, it was perceived as easy to wear with a good fit. The combination of tactile and visual information was perceived as good if the visual information was retained as a clarification of the tactile order.

Our test subjects gave us a few re-design suggestions:
One subject thought that no more than 5 vibrating signals should be used, another that as little information as possible should be transmitted through the display as he feared that the display should take too much attention from the environment. Other suggestions were that the vibrators should be a bit stronger, more dispersed and have a more distinct difference between the signals. Further comments were that the brace could be smaller and that the display should be turned somewhat so that the user didn't have to tilt his head in a crucial situation.

7.3 Sample loss
Due to a technical failure, one subject were not filmed during test, his performance are not counted in into the percentages. However, he did take the survey and therefore the percentages are counted on 10 subjects and the survey on 11. During the filmed test, one subject did not respond to two of the symbols. The lack of reactions is therefore counted as a wrong reaction. In the survey, one subject did not answer the first question.

8 Conclusions

The tests and surveys have given us some results that confirm our assumptions that an artefact like PalpEye can become useful in a military context. It, however, will need further development on several aspects before it can be used in reality.

The soldiers reacted well, and were very positive to the use of a tactile stimulus to communicate information in an active military context. The test result indicates that an artefact like PalpEye does solve some of the communicative problems soldiers encounter as it was thought to attract the attention of the soldier. Using a combination of one tactile and one visual display communicating the same signal, was perceived as very positive as the visual display enhanced the order given if the subject missed the tactile signal.

An overall reaction to the issue of comfort was that PalpEye had a good fit and was comfortable to wear when properly adjusted. We haven't found any acute physical problems with wearing the prototype, although we need to conduct several more tests, including a longitudinal test to ensure it.

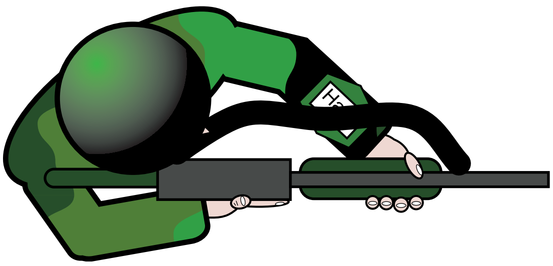


Figure 8.1:Weapon strap Covering Display

In one instance the soldiers' present equipment and PalpEye was found to counteract with each other, as the weapon strap partially covers the display (Figure 8.1). This issue has to be addressed in a future development phase.

The majority of the subjects felt the vibrations clearly, although the symbols were more dubious in their design. Although several subjects claimed that it was hard to remember the symbols, the test result showed mean correct reactions of 51,25%, without using the display and a 100% correct reaction with a display. We feel these results as promising considering the short learning time each subject had, if the artefact was introduced earlier in their training, perhaps as early as the first day, we are confident that the symbols are learnable. Anyhow, there is an acute need for developing a good symbol language together with soldiers of different levels and experiences to ensure that each tactile symbol maps the weight and feel of the vocal and visual command. The amount of symbols that can be learned is a factor that needs further research.

Regarding the theoretical basis upon which PalpEye rests we believe that it is ubiquitous since it is present to the user in his context wherever he may be. It is a wearable, computer based, artefact that has some of the properties mentioned in the framework of Calm Technology. PalpEye needs to be a peripheral artefact that, when needed, attracts the users attention due to the context and nature of soldiers Task Environment, which is highly demanding, both physical and psychologically, and therefore it is necessary that a wearable device does not interfere or increase the cognitive load to a level that can produce a lower performance from the soldier.

We believe that a context awareness is essential for an artefact such as PalpEye, but how this is to be implemented we cannot conclude in the course of this report. The awareness is not limited to knowing when and how information will be presented to the user, but also to whom and the level of detail and awareness of the changes in the context were the artefact is presently used in. The Ideal PalpEye will incorporate some of these issues.

8.1 Ideal PalpEye

The ideal PalpEye takes its base in the current version of PalpEye, but is naturally an extensive evolution in several aspects.

Developing PalpEye we have used quite crude electronics, although there are many alternative choices on the standard market for electronics. One of the most acute and important problems of electronics is the sensitivity to the severe conditions the military environment poses. By using mobile technology and develop casings, we can go around some of the problems with standard electronics, such as the ability to withstand moisture or dirt. However, other problems will probably render COTS-technology as useless in the long run.

There have been several attempts to make tactile displays using different tactor technologies. Under the construction and testing of PalpEye we found that the size of the vibrators was a large constraining factor of the total size of PalpEye. If the size of each tactor could be reduced to preferably less than 5 mm, and have a pointing tip, the vibrations could get more exact and PalpEye as a whole could get very much smaller.

For PalpEye we used vibrating motors, due to low cost and easy access. The ideal tactor however needs to stimulate more types of skin receptors, than vibrators, in order to create a reliable stimulus. We have concluded that MEMS technology shows a great potential for the future on creating a tactor. MEMS can be made small enough with satisfying power consumption. Currently there are obstacles to overcome before using this technology, such as development and manufacturing technologies.

When using standard textiles developed by, or already in use in the military was a way of ensuring that at least the protective properties would meet our demands. In an ideal version of PalpEye, textiles need to undergo rigorous tests and probably be developed especially for PalpEye. The ideal textile would be one where the chords and/or the vibrators are integrated into the fabric, leaving the outside completely smooth, although still soft and breathable to be comfortable.

For PalpEye or a similar application E-ink present the most suitable display technology to date, since it shows high contrast, low power consumption and a passive memory (the display retains the latest presented data on screen without any power consumption). It is desirable that the visual display has got a memory, which means that the latest image is remained until a new image is presented; e.g. to have the functionality of a Post It to relieve the soldiers short term memory (Baddeley, 1998). If the application will need color, video capability, a high contrast map or any graphical data, OLEDs and similar technology is probably best suited as of today.

Further on, issues dealing with context awareness has to be implemented in order to enable a deeper usability of the artefact. When and how to present the right information is not a trivial question and needs further research. This will in turn render questions and possibly even solutions to adopt Calm Technology as a suitable framework for artefact like PalpEye.

9. Discussion

PalpEye stir around in the pot of wearable computers for the future dismounted soldier. During the course of the project we found ourselves surrounded by researchers that believe in the power of the eye. Everywhere gadgets that crave the attention of an already occupied perceptual modality emerged. It is new sights; helmet mounted displays and goggles as well as auditory devices such as head-sets, sounds that give cues about location and much more. When a soldier is engaged in hostile fire, the sounds and sights are overwhelming and presents both psychological as well as physical obstacles. The more we dug the more we believed that there is a great need to look beyond the visual and auditive perceptual senses in order to communicate between soldiers.

9.1 What has been learned

The most prominent problem we encountered during this project was the lack of time, both when developing and when testing the prototype.

Using COTS-technology, the possibility to develop for an extreme environment became more or less impossible, since the technology in most cases is too sensitive to survive rugged conditions. We focused instead upon designing with adaptability in mind, and using the best material we could find in the limited timeframe we had. The prototypes became more a tool to communicate and test the idea in laboratory conditions rather than in its proper context. Consequently we thereby had to change our plans of doing a true context test, with a base in bodystorming. Instead we chose to divide the test into two parts, which we later on found to be an advantage in this stage. By using a controlled environment we excluded the influence of external conditions which could give unexpected answers to our test. This, however, is a double edged sword; we cannot really say anything about how the functionality and usability does work in a proper context.

Using a laboratory environment and persons with good contextual knowledge to this pilot test have given us sufficient data to believe that vibrations probably are very interesting to investigate further, although we cannot say it for a fact.

A quite narrow time frame made us choose to conduct the three parts of the test simultaneously. When doing this we noticed that being only two test leaders working on separate parts; we were at least three persons short. It would have been very useful to have a minimum of two persons, preferably three, conducting each test, to ensure that no data was missed. While analyzing the tests we also discovered that some of our questions in the concluding survey were ambiguous in their wordings, as some of the answers were not as expected. We therefore need to better specify each question in the next tests. To foresee these problems, a pilot test could have been done early in the development phase.

9.2 Future works

PalpEye is a basic research and has outlined some of the problems with wearable computers in a military context as well as issues with tactile interfaces and technologies regarding stimuli of the same. There are many factors that need to be embedded into a project such as PalpEye. A rigid timetable is hard to create, due to the complexity of a further development. In the first generation of PalpEye we can see that its primary function is to assist and augment the traditional communication in order giving between members of a group through tactile and visual channels. This is something that can be developed further into a PalpEye that can use the full spectrum of human cognitive abilities.

In a groupware system such as PalpEye it is important that the system gets knowledge about the context in which the individual user resides in. An artifact such as PalpEye will need context-awareness if the concept of usability and Calm Technology is to be regarded. Much information is gathered from many different sources and a filtering of it is crucial. When, what and how information is to be presented demands a lot from the system. Users are occupied with their task and should not be concerned with the configuration of information retrieval. Therefore it's important to analyze and evaluate not only the user needs but also the demands of use. Can the soldier deal with the increased information load and still be operational and staying alive?

We also have to understand the impact of placing an artifact into that environment, and in the context of use. When the introduction of a wearable computer artefact is made it changes more than just the wearer. We believe that it will change strategies, communication patterns and much more. Tests on these factors are important and can only be done using longitudinal studies.

We have below listed some additional ideas and thoughts that needs to be addressed in a further development.

- PalpEye II could give more visual information such as GPS, damage control, bio-signals to monitor fatigue, pulse or breath. PalpEyeII therefore requires a bendable display that is more rigid and developed for mobile military use; that is, worst possible conditions.

- Our usability testing scenario did not be including an endurance test to see if the error rate increases with fatigue. This can be further investigated to ensure that tactile perception is trustworthy as an information appliance for critical information.

- Further investigation on Signature Management needs to be conducted in order to fully understand how electronic devices can be concealed from the enemy. In here we mean visual displays, tactors and so on.

- Development and testing of different tactors in order to confirm the best placement and source of stimuli.

- New material must be able to be used wherever the soldier works, in water, in an urban environment, forests, deserts and many more. The environment constantly changes; rain, fog, darkness, chemical warfare and much more.

We believe PalpEye has got a future. Most of the ongoing research on integrated soldier systems involves helmet mounted displays, video cameras and other visually demanding artifacts interfering with an already occupied perceptive module. Therefore we feel that there is a need to find other solutions, as information will be conveyed in all possible contexts, whether the soldier is standing still or on the move. The environment of the dismounted soldier is not to be taken lightly.

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Used Electronic components

When creating the high fidelity prototype, COTS electronic were used. All electronic circuits can be found in electronic stores.

Arm Placed Device

Name	Spec.	
10 pcs	Pancake Vibrator	Jameco*[1] Part #185228
1 pcs	LCD Display 16x2 digits Blue	2x16, Part # 6-160*[2]
1 pcs	Serial Board	Standard (BPK) LCD Driver Board

Electronic Box

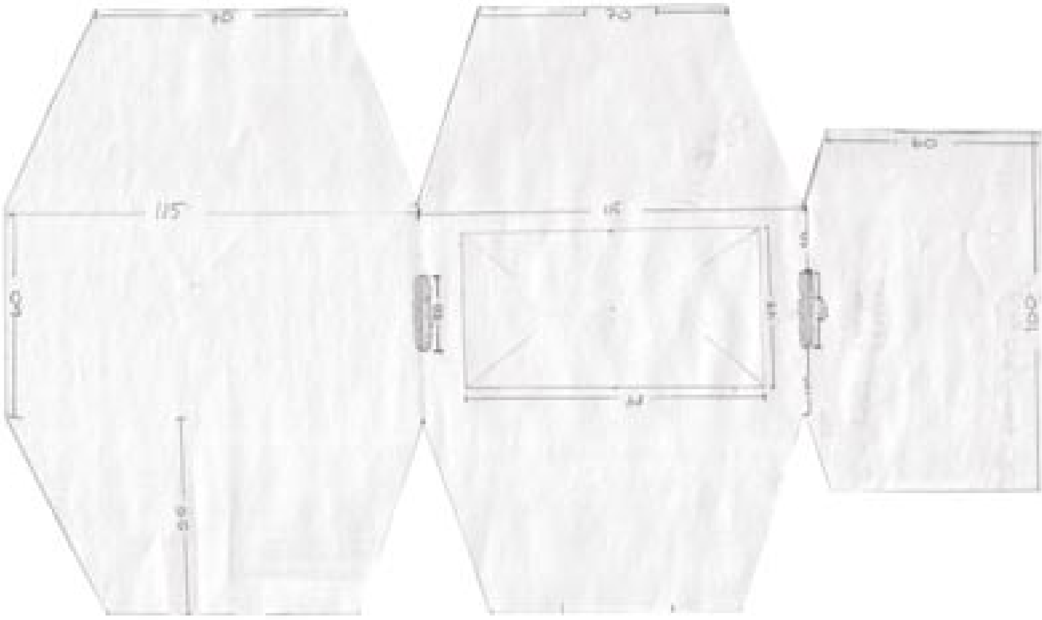
Name	Spec.	
2 pcs	Darlington Drive	ULN2003A DIL16, ELFA*[3]: **73-099-33**
1 pcs	Microcontroller	BX 24
1 m	Power Cord	2 parts 0.75mm
1 m	Cord	16 parts
1 pcs	Battery	9v

Remote Control

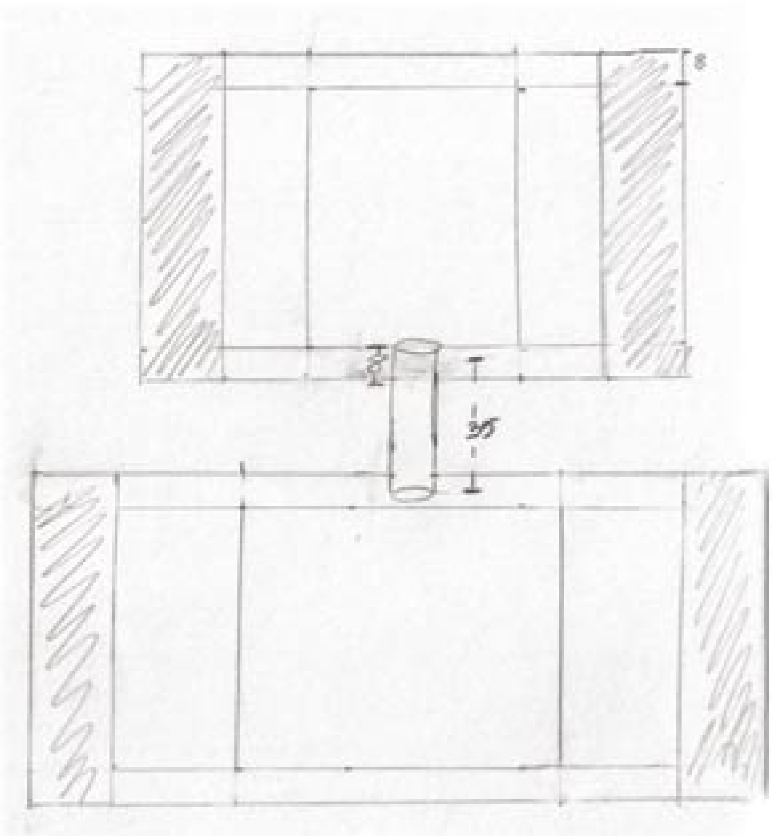
Name	Spec.	
4 pcs	Push Buttons	TP32P00, ELFA: **35-246-00**
1 pcs	Red 5 mm	EL332HD Red, ELFA: **75-006-30**
1 m	Cord	8 parts

*[1] - Jameco - www.jameco.com
*[2] - Milford Instruments - www.milinst.com
*[3] - ELFA - www.elfa.se

Patterns

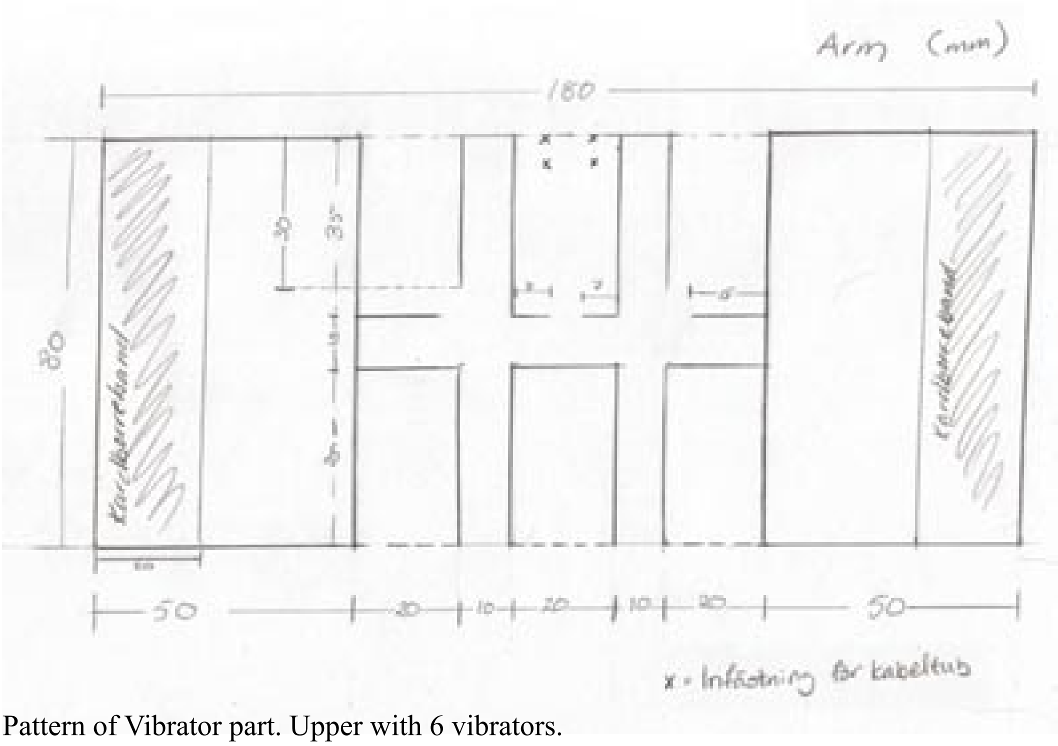


Pattern of Display part.

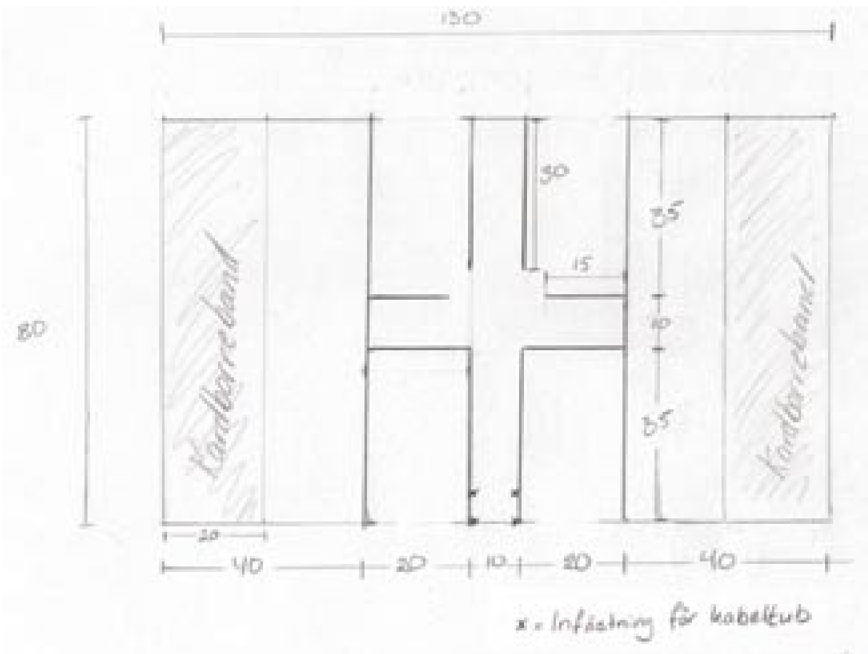


Pattern of Vibrator part. Both upper and lower.

Patterns

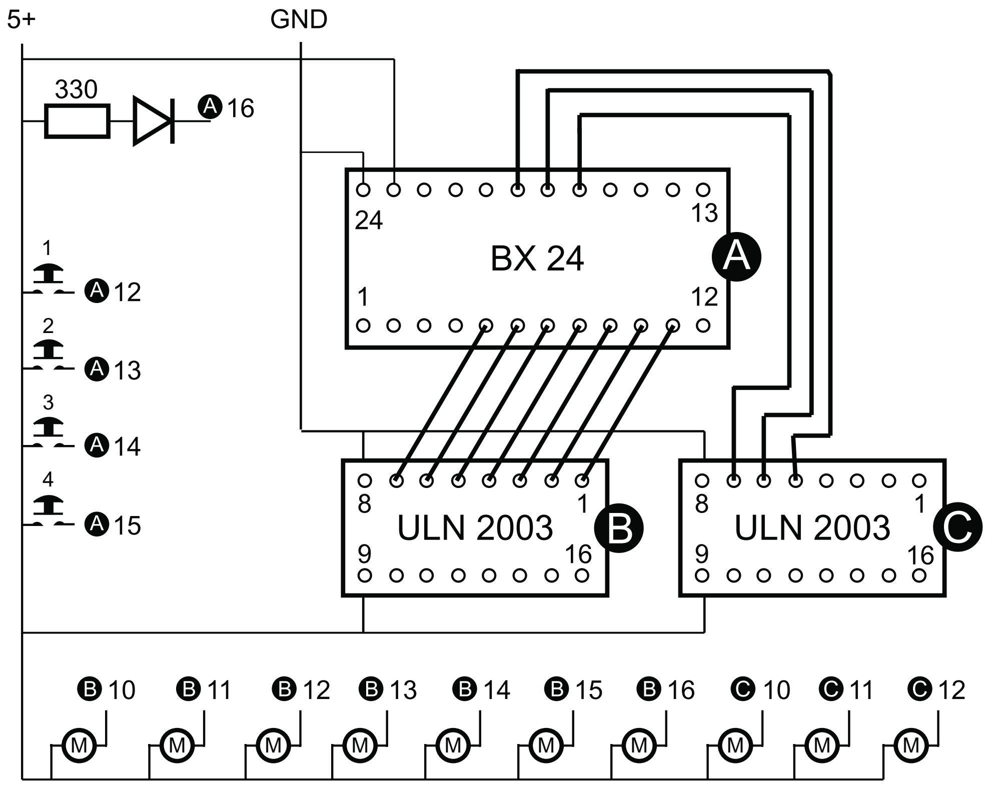


Pattern of Vibrator part. Upper with 6 vibrators.



Pattern of Vibrator part. Lower with 4 vibrators.

Circuit drawing



Appendix D

Code

```
'Vibrator Handling

Option Explicit
'****************** Tactor Variables **********************************

' Tactornames(an abbreviation of placement) set to I/O pins,
' seen from above with cord tube placed upwards (Cord color)
Private Const WUL as Byte = 9      'Wrist Upper Left        (white/green)
Private Const WUR as Byte = 10     'wrist upper right (purple)
Private Const WLL as Byte = 11     'wrist lower left (grey/purple)
Private Const WLR as Byte = 12     'wrist lower right (brown)

Private Const AUL as Byte = 13     'arm upper left (blue)
Private Const AUM as Byte = 14     'arm upper middle (grey)
Private Const AUR as Byte = 15     'arm upper right (white/yellow)
Private Const ALL as Byte = 16     'arm lower left (yellow)
Private Const ALM as Byte = 17     'arm lower middle (white)
Private Const ALR as Byte = 18     'arm lower right (pink)

Private Const TactorArrayLength as Integer = 10     'Current amount of tactors are 10,

'no larger array needed at this moment

Dim TactorArray (1 To TactorArrayLength) as Byte '10 data entries available

'****************** END TACTOR VARIABLES **********************

'***************** Private tactor procedures **********************

' shortPulse and longPulse are procedures taking an array and calls
' a procedure Pulser, which creates the pulse. The only difference
' between them is the sleep time before StopTactors are called.
Private Sub  shortPulse(ByRef TactorArray() as Byte)

        Call Pulser(TactorArray)
        Call StopTactors

End Sub


Private Sub  longPulse(ByRef TactorArray() as Byte)

        Call Pulser(TactorArray)
        Call sleep(0.5)
        Call StopTactors

End Sub
```

Appendix D

```
‘ Procedure Pulser runs through the pre-filled tactorarray and runs
‘ appropriate vibrator
Private Sub Pulser(ByRef TactorArray() as Byte)

        Dim i as integer
        For i= 1 To TactorArrayLength
                If (TactorArray(i) > 0) Then
                Call PutPin (TactorArray(i), 1)
                End If
        Next

End Sub

‘StopTactors closes connection between vibrators and BX24 chip
Private Sub StopTactors()

        Dim i as integer
        For i= 1 To TactorArrayLength
        If (TactorArray(i) > 0) Then
                        Call PutPin (TactorArray(i), 0)
                End If
        Next
End Sub



‘ Forward fills the TactorArray with appropriate tactors
‘ (the “end”-tactors)and gives a short pulse, twice

Public Sub Forward()

        Call ClearTactorArray

        Dim     i as Integer
        For i = 1 to 2
                TactorArray(1)= ALL
                TactorArray(2)= ALM
                TactorArray(3)= ALR
                Call shortPulse(TactorArray)
                Call ClearTactorArray

                TactorArray(1)= WUL
                TactorArray(2)= WUR
                Call shortPulse(TactorArray)
                Call ClearTactorArray
        Next
                Call ClearTactorArray

End Sub
```

Appendix D

```
' Fire gives one short pulse on upper part of the arm
Public Sub Fire()

        Call ClearTactorArray
        TactorArray(1)= AUL
        TactorArray(2)= AUM
        TactorArray(3)= AUR
        Call shortPulse(TactorArray)
        Call ClearTactorArray

End Sub
' Stop firing gives a long pulse on the arm and wrist
' simultaniously, twice
Public Sub CeaseFire()

        Call ClearTactorArray
        TactorArray(1)= ALL
        TactorArray(2)= ALM
        TactorArray(3)= ALR
        TactorArray(4)= AUL
        TactorArray(5)= AUM
        TactorArray(6)= AUR

        TactorArray(7)= WLL
        TactorArray(8)= WLR
        TactorArray(9)= WUL
        TactorArray(10)= WUR
        Call longPulse(TactorArray)
        Call longPulse(TactorArray)
        Call ClearTactorArray

End Sub


' Low position uses 2 short pulses moving sideways on the wrist,
' left to right, 2 times
Public Sub LowPosition()

        Call ClearTactorArray
        Dim     i as Integer
        For i = 1 to 2
                TactorArray(1)= WUR
                TactorArray(2)= WLR
                Call shortPulse(TactorArray)
                Call ClearTactorArray

                TactorArray(1)= WUL
                TactorArray(2)= WLL
                Call shortPulse(TactorArray)
                Call ClearTactorArray

        Next
        Call ClearTactorArray
```

```
End Sub
' Fills TactorArray with zero's, thereby emptying it
Private Sub ClearTactorArray()

        Dim i as Integer
        For i = 1 to TactorArrayLength
                TactorArray(i) = 0
        Next

End Sub

*************** END PRIVATE TACTOR VARIABLES ********************'
Buttons and LCD

Option Explicit

'****************** Variables ******************************************

' Buttons set to I/O pins
Private Const button1 as Byte = 6
Private Const button2 as Byte = 7
Private Const button3 as Byte = 8
Private Const button4 as Byte = 19
Private Const LedRed as Byte = 20
Private Const LCDTx as Byte = 5

' Define Com3 with buffer sizes
Dim Com3In(1 to 15) As Byte
Dim Com3Out(1 to 40) As Byte

' Define the LCD control constants used, predetermined from manufacturer
' ControlBit needed since the LCD runs by a Stamp-protocol
' and not by BX24-protocol
Private Const ClearLCD As Byte = 1
Private const ControlBit as Byte=254

'****************** END VARIABLES **********************************

'****************** Private button and LCD procedures *********************

'Initiate buttons to the BX24-chip
Public Sub InitButtons()
        Call PutPin(button1, bxInputPullup)
        Call PutPin(button2, bxInputPullup)
        Call PutPin(button3, bxInputPullup)
        Call Putpin(button4, bxInputPullup)

        Call PutPin(LedRed, 1)
        Call PutPin(LedRed, 0)
```

```
End Sub


Sub InitLCD()

        Call delay (0.5)                        'Wait 1/2 second after power up for
LCD to stabilize
        Call OpenQueue(Com3In, 15)   'Open Com3-queues with buffers, 15 data places
in inqueue
        Call OpenQueue(Com3Out, 40)          '40 in outqueue
        Call DefineCom3(0, LCDTx, bx1000_1000)     'Set Com3 to Inverted Logic, 8
Data Bits, No Parity,
                                                                            'Pin5
TX, 0 = NO RX pin
        Call OpenCom(3, 9600, Com3In, Com3Out)' Open Com3

End Sub

'*********** END PRIVATE BUTTON AND LCD PROCEDURES ***************


' Handles pressed buttons and sends appropriate messages to LCD
Public Sub ButtonHandlerTask()

        Call sleep(0.0)                                 'Allow other tasks to run
                If (GetPin(button1) = 0) Then    'Read button1 (Forward order)

                        Call PutPin(LedRed, 1)           'turn on control LED.
                        Call PutQueueStr(com3Out,Chr(ControlBit) & Chr(ClearLCD))
'Clear Screen to prepare

                                ' for new info
                        Call delay(0.1)
                        Call PutQueueStr(Com3Out, "    Framat!")
                        Call Delay(0.5)
                        Call Forward
                        Call sleep (0.5)                          'Pause 100ms for button
to de-bounce
                        Call PutPin(LedRed, 0)           'Turn off ControlLed
                        Call PutQueueStr(Com3Out,Chr(ControlBit)&Chr(ClearLCD))

                ElseIf (GetPin(button2) = 0) Then         'Read button2(Fire) and turn on/
off red control LED
                        Call PutPin(LedRed, 1)
                        Call PutQueueStr(Com3Out,Chr(ControlBit)&Chr(ClearLCD))
                        Call delay(0.1)
                        Call PutQueueStr(Com3Out, "     Eld!")
                        Call Delay(0.5)
                        Call Fire
                        Call sleep (0.5)
                        Call PutQueueStr(Com3Out,Chr(ControlBit)&Chr(ClearLCD))
                        Call PutPin(LedRed, 0)
```

```
                ElseIf (GetPin(button3) = 0) Then          'Read button3(Cease fire) and
turn on/off red control LED
                        Call PutPin(LedRed, 1)
                        Call PutQueueStr(Com3Out,Chr(ControlBit)&Chr(ClearLCD))
                        Call delay(0.1)
                        Call PutQueueStr(Com3Out, "  Eld upphor!")
                        Call Delay(0.5)
                        Call CeaseFire
                        Call sleep (0.5)
                        Call PutQueueStr(Com3Out,Chr(ControlBit)&Chr(ClearLCD))
                        Call PutPin(LedRed, 0)

                ElseIf (GetPin(button4) = 0) Then          'Read button4(Low Position)and
turn on/off red control LED
                        Call PutPin(LedRed, 1)
                        Call PutQueueStr(Com3Out,Chr(ControlBit)&Chr(ClearLCD))
                        Call delay(0.1)
                        Call PutQueueStr(Com3Out, "     Skydd!")
                        Call Delay(0.5)
                        Call LowPosition
                        Call sleep (0.5)
                        Call PutQueueStr(Com3Out,Chr(ControlBit)&Chr(ClearLCD))
                        Call PutPin(LedRed, 0)

                End If
        Call Delay(0.1)                 'Pause 100 ms for button de-bounce.


End Sub

'Main
Option Explicit

****************Private main procedures******************
' Initialises buttons and LCD
Sub Init()
        Call InitLCD()
        Call InitButtons()
End Sub
****************END PRIVATE MAIN PROCEDURES********************


' Initialises buttons and LCD and listens after a button pressed
' by looping the ButtonHandlerTask
Sub Main()

        Call Init()

        Do
                Call ButtonHandlerTask
        Loop

End Sub
```

User Test - Questions

1. **I feel PalpEye on my arm(dubious), 1 non-answer**
   60% agrees fully, 10% agrees partially, 30% does not agree

2. **PalpEye feels uncomfortable**
   9% agrees fully, 9% agrees partially, 82% agrees slightly or not at all

3. **I feel that PalpEye is moving(dubious)**
   27% agrees fully, 9% agrees partially, 64% agrees slightly or not at all

4. **PalpEye gives me discomfort**
   100% agrees slightly or not at all

5. **PalpEye are painful to wear**
   100% agrees slightly or not at all

6. **Wearing PalpEye makes me feel physically different**
   18% agrees partially, 82% agrees slightly or not at all

7. **PalpEye makes me change my movements**
   9% agrees fully, 91% agrees slightly or not at all
8. **PalpEye is a hinder to my movements**
   100% agrees slightly or not at all

9. **My movements are constricted by PalpEye**
   18% agrees partially, 82% agrees slightly or not at all

10. **I felt the vibrations**
    100% agrees slightly or not at all

11. **. I perceived the different combinations as clear**
    45% agrees fully, 9% agrees partially, 36% agrees not at all

12. **. The display helped me to understand the order**
    91% agrees fully, 9% agrees partially

13. **PalpEye made me react**
    100% agrees fully

14. **Jag kunde känna den enskilda vibratorn**
    73% agrees fully, 18% agrees partially, 9% agrees slightly or not at all

15. **I perceived the vibrations as a disturbance**
    9% agrees fully, 9% agrees partially, 82% agrees not at all

16. **I perceived the vibrations as unpleasant**
    100% agrees slightly or not at all

17. **I think that vibrations could be a good way of getting my attention**
    91% agrees fully, 9% agrees partially

18. **The display helped me to determine when a change occured**
    73% agrees fully, 27% agrees partially

Appendix E

Sätt ett kryss i den position på skalan som bäst motsvarar din åsikt och värdering.

Jag kände vibrationerna

instämmer inte alls — instämmer helt

Jag upplevde de olika kombinationerna som tydliga

instämmer inte alls — instämmer helt

De olika vibrationerna var lätta att skilja åt

instämmer inte alls — instämmer helt

PalpEye fick mig att reagera

instämmer inte alls — instämmer helt

Jag kunde känna den enskilda vibratorn

instämmer inte alls — instämmer helt

Jag upplevde vibrationerna som störande

instämmer inte alls — instämmer helt

Jag upplevde vibrationerna som obehagliga

instämmer inte alls — instämmer helt

Jag tror att vibrationer kan vara bra att använda för att fånga min uppmärksamhet

instämmer inte alls — instämmer helt

Displayen hjälpte mig att avgöra när en förändring skedde

instämmer inte alls — instämmer helt

Appendix E

Sätt ett kryss i den position på skalan som bäst motsvarar din åsikt och värdering.

Jag känner PalpEye på min arm.

instämmer inte alls — instämmer helt

PalpEye känns obekväm.

instämmer inte alls — instämmer helt

Jag upplever att PalpEye rör på sig.

instämmer inte alls — instämmer helt

PalpEye ger mig obehag

instämmer inte alls — instämmer helt

PalpEye är smärtsam att bära

instämmer inte alls — instämmer helt

Att bära PalpEye får mig att känna mig fysiskt annorlunda

instämmer inte alls — instämmer helt

PalpEye får mig att förändra mina rörelser

instämmer inte alls — instämmer helt

Mina rörelser hindras av PalpEye

instämmer inte alls — instämmer helt

Mina rörelser begränsas av PalpEye

instämmer inte alls — instämmer helt

Appendix E

Hur ställer du dig till att använda känsel som kommunikationskälla?

I vilka situationer tror du att en artefakt som PalpEye kan vara användbar?

I vilka situationer tror du att en artefakt som PalpEye kan vara ett hinder?

Har du några övriga kommentarer om tekniken i allmänhet och PalpEye i synnerhet?

Appendix E

Med display

Anv 1.	A	B	C	D	A	B	C	D
Anv 2.	D	A	B	C	D	A	B	C
Anv 3k.	B	C	D	A	B	C	D	A
Anv 4.	B	C	D	A	B	C	D	A
Anv 5.	A	B	C	D	A	B	C	D
Anv 6.	D	A	B	C	D	A	B	C

Utan display

Anv 1.	D	A	B	C	D	A	B	C
Anv 2.	B	C	D	A	B	C	D	A
Anv 3k.	B	C	D	A	B	C	D	A
Anv 4.	A	B	C	D	A	B	C	D
Anv 5.	D	A	B	C	D	A	B	C
Anv 6.	A	B	C	D	A	B	C	D

A= Framåt
B= Eld
C= Eld upphör
D= Skyddsställning