Smart Clothing Prototype for the Arctic Environment

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Abstract: Continuous miniaturisation of electronic components has made it possible to create smaller and smaller electrical devices which can be worn and carried all the time. Together with developing fibre and textile technologies, this has enabled the creation of truly usable smart clothes that resemble clothes more than wearable computing equipment. These intelligent clothes are worn like ordinary clothing and provide help in various situations according to the application area. This paper describes the design and implementation of a survival smart clothing prototype for the arctic environment. Concept development, electrical design, and non-electrical features are discussed. The suit provides communication, positioning, and navigation aids for the user. Depending on the measurements of the human and the environment, the suit decides whether an emergency message should be sent. The user can control the system with a user interface called a Yo-Yo. The functionality of the suit has been tested in an arctic environment.

Keywords: Electrical heating; Smart clothing; User interface; Wearable computing

1. Introduction

Wireless communication and wearable computers coupled with clothing forms a new approach to wearable computing. This so-called "smart clothing" has become a potential alternative for a wide range of personal applications, including safety and entertainment as well as applications requiring privacy. The basis for smart clothes is ordinary clothing, which is augmented with electrical or non-electrical components. Also the fabric of the clothing may itself be intelligent. Based on these, we get an intelligent garment that can better fulfil its primary function as clothing, and also give some added value to a user.

Electronically implemented intelligence in smart clothing includes electrical components such as processors, sensors and communication equipment which help the clothing to adapt to the changing environment and the user's needs. On the other hand, non-electrical functions may also provide necessary tools for the user to survive in uncommon situations. An intelligent fabric may itself change its colour or structure according to changing weather conditions. The goal will be the same in all cases and only the methods vary.

Smart garments are intelligent products that provide platforms for the development of new innovative applications. Clothing may act as a communication medium, an information content platform, or an interface for future ubiquitous computing devices. Smart clothing can promote safety with the help of different alarm, positioning and sensor systems. Clothing may also function as a working aid, e.g. smart clothes can perform physiological measurement and data collection tasks for doctors or offer communication help for maintenance workers.

The process of designing smart clothes involves many fields and is very demanding. Totally different skills are needed compared with ordinary electrical or clothing design. To gain good results, we got together researchers from different areas for the same project. We have electrical and clothing designers, but also people from fibre and textile design, computer science and industrial design. As several people with different skills were needed in the project, the importance of co-operation was emphasized. However, this paper concentrates on the electrical design. Information on textile material selection, clothing design and washing tests can be read in the previous conference paper

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published by the Institute of Electrical and Electronics Engineers [1].

In Section 2 we give a survey of the previous work related to smart clothing. In Section 3 we discuss the project background. In Section 4 the requirements for the system are given. On the basis of these requirements, we give a description of the design and implementation of a smart clothing prototype, concentrating on electrical design, in Section 5. User interface design is discussed in Section 6. The testing environment, test methods and main results are presented in Section 7. In Section 8 we discuss electrical heating, which has been studied more since the prototype has been implemented. Section 9 is the concluding section.

2. Related Work

There are distinctions between wearable computing and smart clothing. Although the relevant fields study the capability of users to wear intelligent systems, there are differences in both the technology and the way of using the wearable equipment. However, these fields also have much in common, and the same research groups often study the field of wearable technologies as a whole. Mizell [2] introduced the terms "Tool Model" and "Clothing Model" to describe the different usage models of wearable systems. During the International Symposium of Wearable Computers (1997) at the Massachusetts Institute of Technology (MIT), there was a fashion show in which several well-known fashion designers showed their visions of wearable technology of the future [3]. Many of those garments were closer to smart clothing than wearable computing.

Since their first appearance in 1993 [4], many universities, including MIT [4], Carnegie Mellon University (CMU) [5], Georgia Tech [6] and Tampere University of Technology [7], have actively studied wearable computing. A few commercial wearable computers are available, e.g. from Via Inc. [8] and Xybernaut [9]. The research has concentrated predominantly on the technology of wearable computers and their applications, which are more or less like office computer applications, possibly utilising mobile communication or positioning ability. Steve Mann has carried out extensive work in the field of making computer systems wearable [10]. Inspired by still-life and landscape imaging, he built a wearable personal imaging system. In addition to wearability, Mann has also paid attention to social aspects of computer systems.

Although the smart clothing area is new, several research groups and companies have studied the different aspects of smart clothing. Probably the best-known example of smart clothing is a textile keyboard and a synthesizer embedded into a denim jacket [11]. Intelligence in the form of electrical components has also been embedded into other pieces of clothing, e.g. gloves [12], ties [13], suspenders [14], undergarments [15] and footwear [16].

ElectroTextiles Company Limited [17] has adopted another view in the development of smart clothes. They started by introducing new functionality into textile material without compromising other clothing-like properties such as washability and flexibility. The goal is to produce textile material that is suitable for the attachment of the traditional electric components. The textile would serve as a signal and power carrier. ElectroTextiles is already marketing a textile keyboard that can be used with a personal digital assistant and folded away after use.

Farringdon et al. [18] describe a wearable sensor jacket developed at Phillips. They emphasize wearability properties. Although the jacket has several sensors, it is very textile-like. The wires are implemented with conductive fibres knitted into the cloth. They envision applications where the sensor jacket is used to supply context awareness information to other processing devices such as a wearable or a laptop computer. Philips Research together with Levi Strauss [19] have also introduced the Industrial Clothing Design (ICD+) concept where a premium sports jacket has an integrated MP3 player, a headset, a mobile phone with speech control, and a personal area network.

Lind et al. [20] at Georgia Tech have developed a sensor T-shirt which can be used in combat to measure how a soldier is wounded. The system is capable of sensing the hitting point of a projectile in the body. The shirt has a mesh of optical and conductive fibres integrated into the woven structure of the textile. A conductive path is broken when a shot strikes the shirt.

MIT has introduced a smart vest concept.

The platform for the smart vest is a lining composed of a lightweight mesh [21]. This kind of structure provides a medium for integrating electrical units with flexible interconnections. Although the system is a traditional wearable computer, much attention is paid to wearing comfort.

CMU has done extensive research on wearability. This is a feature that is common for both wearable computing and smart clothing systems. Results from their work were presented at the Second International Symposium on Wearable Computers in Pittsburgh [22]. They introduced guidelines for adding solid or flexible components into suitable locations on the human body.

The Defence Clothing and Textile Agency has done research on material development for smart clothing. They have studied shape memory materials [23], active ventilation, heat transfer through garments, and reactive waterproof materials [24]. Gore [25] has developed many new materials based on polytetrafluoroethylene (PTFE) technology and has concentrated on waterproof, windproof, and breathable fabrics. Gore has also introduced smart clothing products such as the S-Key glow for skiers.

Reima-Tutta [26] were scheduled to launch probably the first commercial smart clothing product in August 2001. It is called the Reima Smart Shout and it provides a new method for group communication. The clothing itself is a two-inch wide textile band which is worn over one shoulder by crossing the chest. The band has a pocket for an ordinary mobile phone. A connector inside the pocket hooks the phone to the electronics. The user interface is very textile-like since it only consists of two straps. When one strap is pulled, the band distributes its phone number to all similar bands nearby using a short-distance radio. At the same time, the band receives phone numbers from other users, and a group is formed. When the user wishes to send a voice message, he or she pulls the other strap and speaks the message. The Reima Smart Shout digitises the message and saves it. Then the band automatically sends the message to all bands belonging to the same group by using a mobile phone. The idea is very simple, but the usage differs radically from the usage of a normal mobile phone for sending a message to a group in active situations like snowboarding or rock climbing.

3. Project Background Information

The smart clothing project started in November 1998 as co-operation between the Reima-Tutta Corporation, the University of Lapland, and Tampere University of Technology. Later, DuPont, Nokia, Polar Electro and Suunto participated in the project. The project was partly founded by the Technology Development Centre of Finland, and ended in March 2000.

The objective of the smart clothing project was to study different possibilities of using information technology, electronics, and advanced fibre and textile materials to develop better clothes. As one of the results, a smart clothing prototype has been developed. The prototype is a survival suit intended especially for experienced snowmobile users to prevent accidents and help survival in case an accident occurs. However, the design is also suitable for other activities, e.g. hiking in demanding conditions.

A snowmobile suit was selected for the target application platform as Reima-Tutta already produces clothing for arctic conditions and snowmobile users. The snowmobile suit also has several advantages that can help in the design process. Snowmobile suits provide good platforms for placing additional components into clothing due to the suits' high volume and weight. This helps the clothing design process and enables the hiding of the components in the clothing without causing any extra bumps in the appearance. The application area also has evident dangers that need to be solved, including e.g. getting lost and danger situations caused by insufficient equipment.

4. System Requirements

Before starting the actual design, it was important to clarify the problem that needs to be solved. It was also evident to set requirements and goals for the prototype. This work started with the determination of user requirements. Our assumptions were that the user knows basic survival skills and his own capacity, has basic first aid skills and can fix common mechanical failures of snowmobiles. With this decision we tried to avoid the situation in which inexperienced users would get a feeling of excessive and false safety while using the suit.

Next we investigated the possible problems that may arise during the use of the garment in arctic winter conditions. The prototype is designed to fulfil these requirements, while being as good and functional to wear as an ordinary snowmobile suit, but also having some new features. The investigation was done by interviewing frontier guards, insurance companies and professional snowmobile drivers. This survey showed that there are seven general problems that users will meet in the field: getting lost, encountering accidents, technical failures of snowmobiles, hostile and unexpected weather conditions, health problems, lack of important equipment, and the problems caused by coldness. It was required that the suit would solve, after a fashion, all these seven problems.

4.1. Design requirements

The basic requirement for the mobile computing system is portability, which means small size, low weight, and low power consumption [27]. Therefore, a limit for extra weight was set. Usually, a snowmobile suit weights about 3.5 kg. Our aim was not to exceed 1 kg extra weight.

An important requirement is also the operating time, which in this kind of application tends to be the most limiting factor. It was required that the suit should work for 24 hours on one charge; therefore, to achieve minimum power consumption in each device was a guiding principle in the electronics and software design.

A user interface (UI) is very challenging to design because of the operating environment, and the mobility and user-friendliness requirements. The UI should enable selection from menus and basic text-entering. For these reasons, two demands were set: first, the user should be able to use the interface with gloves on because of the hostile arctic environment; secondly, the interface should be functional for both left- and right-handed people.

A very important requirement for the suit is also wearability, which means that the wearing comfort of the system must not be sacrificed. In our case this means that additional electrical or non-electrical components must not disturb the user. Location of the components has to be chosen in such a way that the suit is also comfortable to wear during demanding tasks, such as stretching and creeping.

4.2. Environment limitations

The harsh winter environment sets its own limitations and demands for both electrical and clothing design. Electrical components should endure a wide range of operating temperatures and changing humidity. Components are chosen to endure temperatures from –20°C to +50°C. On the other hand, the textile materials should also adapt to changing weather conditions by covering the user and maintaining the temperature balance of the user and conditions of thermal comfort. The components that are integrated into the textile's structure need to be machine washable. The components that are detachable need not endure submersion in water, but to provide reliable functionality it is necessary to protect all the electrical parts against humidity and mechanical stress. Also non-electrical parts should be cushioned and covered so that wearability of the clothes is not impaired.

5. Designed Prototype Suit

The suit consists of a two-piece set of underwear, a supporting structure, and the actual snowmobile jacket and trousers. The garment is capable of giving information about the wearer's health, location and movements. With several integrated sensors it is possible to monitor a user's condition and position. If the user meets with an accident or other abnormal situation, the suit will inform an emergency office or activate another preselected phone number via the Short Message Service (SMS) of the Global System for Mobile (GSM) communication. The user can also send the emergency message himself. The message contains the current coordinates of the user's position and an emergency reason code, which in our case refers to an injury situation or to a technical failure of a snowmobile. After the emergency message has been sent, it is also possible to request additional information from the suit. To this request the suit responds by sending data on the user and environmental measurements. The coordinates are acquired using the Global Positioning System (GPS).

Alarm messages are divided into three categories. Automated emergency messages will be sent if data from sensors are abnormal and the user does not react to light and tone wake-up impulses. If the alarm is false, the user can prevent sending of the message within one minute by clicking the button of the UI. If the user does not cancel the message, it will be sent to a GSM number that is preprogrammed to the memory of the Central Processing Unit (CPU). This will facilitate the user's efforts to send a message in the case of an injury. The user has only to select the correct menu and click the button. Other kinds of alarm messages are not allowed.

5.1. Supporting structure

To maintain the look of ordinary clothing, good wearability, and comfort, the electronics are not sewn into the garment shell. A detachable supporting structure is constructed between the jacket's coating and lining to carry the weight of the devices. The supporting structure, illustrated in Fig. 1, can be adjusted for different body types and can be worn tight or loose. It attaches with two loops on the shoulders and two zippered shafts in the front.

Electrical components are divided into several small units and spread out over the user's upper body to gain in flexibility and to lessen unnecessary strain on any single part of the body [22]. The placement of the electrical components can be seen in Fig. 1. Batteries are placed near to the body so that they can be kept in a warm place and proper operation can be ensured. The electronics itself is a source of heat, which may affect body temperature balance and the thermal comfort of the user.

Positions of the components are chosen according to guidelines given in the study of Gemperle et al. [22]. Most of the components in the supporting structure are placed onto the rear and front ribcage and waist. The biggest difference between our placements and CMU's guidelines is that we have also used the shoulder area. That was a compromise that we had to make to gain easier and more reliable wire connections. Six voluntary test subjects tested the supporting structure with three different component placements. The study was done at the University of Lapland. The results showed that in the best placement most of the components were on the person's back. Due to the different size of people too wide or too long structures of components are problematic for placing on the body.

5.2. Non-electrical features

The smart clothing prototype includes several added non-electrical features for supporting the user in accidents, or for enhancing the clothing's own functions. These include a transparent map pocket on the front of the left thigh. A special pocket that can be used for melting snow has been added on the front of the right thigh. This pocket is disposable. Matches are integrated into a shin pocket using a waterproof pouch so that they remain functional also after falling into water. Ice spikes integrated into the jacket sleeves assist the user when trying to get out of a hole in the ice. A waterproof and windproof hypothermia bag has also been added to the back pocket of the jacket. The bag is large enough for providing shelter for the user. Finally, the suit

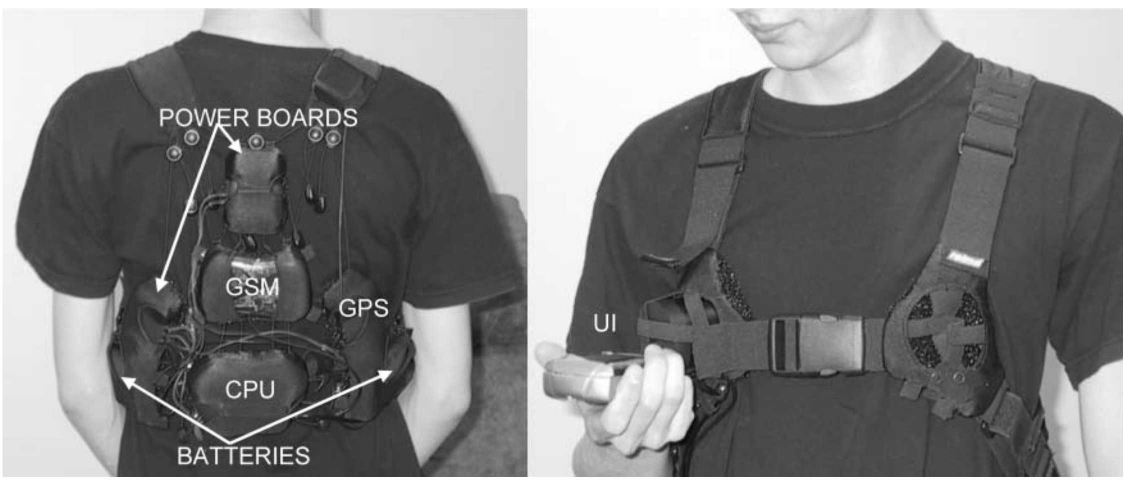

Fig. 1. Supporting structure from the front and back. Placement of the electrical components is also illustrated.

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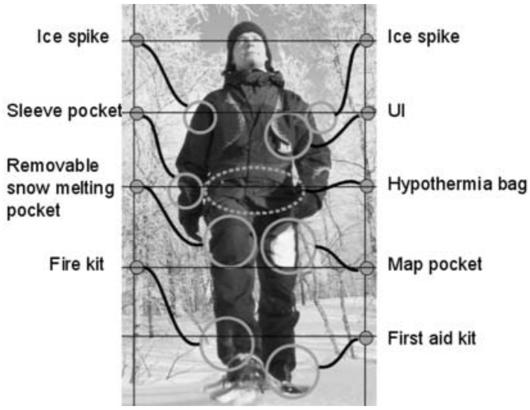

Fig. 2. Picture of prototype and non-electrical features.

includes a special easy access pocket designed for a mobile phone. The picture of the designed suit and non-electrical features are illustrated in Fig. 2.

5.3. Electrical design

The electrical functionality of the prototype suit is divided into four segments: communication, navigation and positioning, user and environment monitoring, and heating. The functional architecture is implemented using GPS for navigation, GSM for communication, and electrically heated fabric panels for heating. The sensor system consists of a heart rate sensor, three position and movement sensors, ten temperature sensors, an electric conductivity sensor, and two impact-detecting sensors. In addition to these, the implementation requires a user interface, a central processing unit, and a power source. Each main module, excluding the sensors and the UI, is placed in the supporting structure. The architecture of the prototype is illustrated in Fig. 1.

Power source

The power source comprises a battery charger unit for utilising a snowmobile as a power supply, a power supply voltage regulator, and two separate battery packages. Ten Toshiba's NiMH cylindrical battery cells are used as a power source in the system [28]. This battery technique was chosen due to its good availability. The battery cells are divided into two five-cell units having a nominal voltage of 12 V and a total capacity of 4000 mAh. The battery packages are connected to the charger unit and the supply unit. The batteries can also be charged from an electrical network via a proper adapter. The batteries are the heaviest parts of the system, weighing about 0.5 kg. The regulator board provides 5 V operating voltage to most of the components of the suit. In addition, there is a 12 V output for the UI, the GSM module and the heating fabric. The power is input to the CPU unit, which forwards the right voltages to the correct components.

GSM

GSM is used for automatic communication after an accident in the case of injury. The communication can also be done by the user if a technical failure or minor health problems are encountered. In addition, a service for weather forecasts is available in Finland. The GSM module used is Siemens's M20T, which is easy to connect to the CPU unit using a serial cable [29]. Because the prototype has been tested and developed in Finland, the communication channel chosen was obvious, but the solution is location and country dependent. The M20T is functional in the GSM900 mobile radio network.

The GSM modem contains interfaces for a supply voltage, an antenna, a serial communication cable and a Subscriber Identity Module (SIM) card. The M20T can be controlled with standard AT commands and a number of manufacturer-specific AT commands. There are also options for a speaker and a microphone in the module, but in the prototype it was decided to use only the SMS. By this decision we tried to prevent the needless use of the phone and the wasting of power. The module has a wide supply voltage range, from 8 V to 28.8 V. In our design we used a 12 V input voltage. In operating conditions the modem needs 200 mA current at maximum, and in standby mode the current consumption is 45 mA at maximum.

GPS

The Conexant's Jupiter GPS module is connected to the system for positioning and navigation tasks [30]. An active antenna for the GPS is placed on the shoulder of the suit, ensuring that the satellite signal can reach the antenna most of the time. The accuracy of the system is approximately 10 m. Jupiter was an obvious choice for the positioning because of the module's small size and our previous knowledge of that particular component. The GPS and an electrical compass assist the user to navigate to a desired point, find other users, or follow back the route travelled.

The maximum power consumption of the GPS module with a 5 V input voltage is 1.2 W, and the power consumption in the standby mode is about 50 mW. The Jupiter GPS module is a single-board receiver engine that is intended for an Original Equipment Manufacturer (OEM) product. Its twelve parallel channels continuously track all the satellites in view. Jupiter has interfaces for a supply voltage, communication cables and an antenna. Communication is established with two asynchronous serial communication ports. The primary serial port is intended for navigation data outputs and the acceptance of commands from the OEM application. The secondary serial port is for differential corrections. In our design, differential GPS is not used, and therefore the other serial port is not connected to the CPU. Additionally, a 100 mA current limiter is used with an active antenna.

CPU

The central processing unit of the system is the central point of the design. All the other modules are connected to the CPU, and also the power is delivered through it. The CPU board has a Hitachi H8/3003 16-bit microcontroller [31]. It runs at 16 MHz and has 1 MB external RAM and 512 kB external flash memory. A large amount of RAM is required for software development, which is done by using the Hitachi EVB3003 evaluation board and its CMON firmware monitor program in the smart clothing CPU [32]. The memory mapping of the CPU is identical to that of the evaluation board.

Since the H8/3003 has only two firmware serial communication ports, and the GSM, GPS, UI and power supply are connected to the CPU by serial ports, a simple eight-channel serial port multiplexer was designed for one port. The multiplexer has a 74HC138A 3/8 decoder chip for multiplexing transmitted data and a 74HC151 8 line multiplexer for received data. The channel is selected with three I/O pins. In addition there is a four-channel RS-232 voltage level converter (Analog Devices ADM211) for those devices that use RS-232 level serial communication [33]. The other serial communication port of the processor was reserved for software development.

Sensors

Monitoring of the user and the environment is done to help the user to survive in three basic situations: impact, falling into water, and injury.

An impact situation is registered by two acceleration sensors that enable three-dimensional measurements. The sensors used are Analog Devices' ADXL150 and ADXL250 that can cover a range of ±50 g [34]. Sensors are connected to the comparator, which generates an external interrupt pulse if acceleration exceeds the pre-set level. All acceleration sensors are placed in the CPU-board.

Falling into water is detected by two conductivity electrodes that are located at the sides of the suit at waistline height. The electrodes measure the humidity of the suit.

An injury situation is first detected by acceleration sensors. These must be more sensitive than the sensors used for impact situations, therefore, three Analog Devices' ADXL105 sensors are adjusted to the range of ±2 g to identify whether the user is moving or immobile and what the posture of the user is [35]. Sensors are connected to the internal A/D converters of the microcontroller. Second, the injury is concluded from the duration of the immobility, posture, heart rate and temperature.

The heart rate monitoring is based on Polar Electro's wireless heart rate monitor [36], with new metal-clad- aramid-fiber electrodes connected to the underwear. The heart rate data is transmitted wirelessly to a Polar receiver module in the CPU board. The wireless transmission is based on a low-frequency magnetic field.

One-wire digital temperature sensors measure microclimate temperatures inside the supporting vest and in the jacket's cover textile. The sensors used are DS1820 sensors manufactured by Dallas Semiconductor [37]. Implementing the one-wire interface with one I/O pin is possible, but because that would have significantly increased the complexity of the software, the one-wire sensors were connected to the serial multiplexer through a serial one-wire line driver (Dallas DS2480) [38]. A one-wire EEPROM chip for storing user-specific data was also added to the one-wire bus.

Heating

Electrical heating in the prototype suit is implemented by using conductive woven carbon fabric panels in the underwear wrists.

The problem is that heating needs a great deal of energy, and batteries may quickly run down. To reduce the power consumption, heating is allowed only after alarm. Constant heating may also passivize the user and in this way affect the user's chances of survival.

Power consumption

In mobile applications the minimising of power consumption has to guide the design process. In our system we used low-power components when possible and utilised the power-saving modes of components. When driving a snowmobile, the power consumption is not an essential concern as we can take power from the snowmobile. In other cases, we have estimated the power consumption of the components, the time that the components are used actively, and the time that they can be in the power-saving mode. By sending one SMS message at two hour intervals, checking the location at ten-minute intervals, using the CPU approximately 5 minutes per hour, and using the sensors and the UI continuously, we can reach 24 hours operating time with one charge. As already mentioned heating is allowed only after an alarm message has been sent. Therefore, it has not been taken into consideration when calculating the operating time.

6. User Interface

The suite has a UI for controlling its electrical functions. The interface can be used for sending emergency messages, for navigation with the aid of the GPS and the built-in electric compass, and for using external services such as local weather reports available through GSM SMS. The UI is illustrated in Fig. 3. In addition to the hand-held device, the suit's user interface can give audio and visual alarms to the user. A small loudspeaker is situated on the suit's collar, and a white Light Emitting Diode (LED) is in the sleeve of the jacket.

The main user interface device is called a *Yo-Yo* interface. The name refers to the construction of the device. The UI unit is held in the hand and the distance between the user and the module is measured by a wire and a winding mechanism. The winding mechanism contains an optical rotary encoder which tells the CPU module the number of turns of wire drawn from the spool. The signal is a phase encoded pulse train, and the counter module in the CPU has a special mode for handling this. One of the difficult parts in the project was to design a reliable winding mechanism which would withstand moisture and very low temperatures without jamming or fractures in the wire. The winding mechanism of the Yo-Yo and the optical rotation encoder are embedded in the clothing.

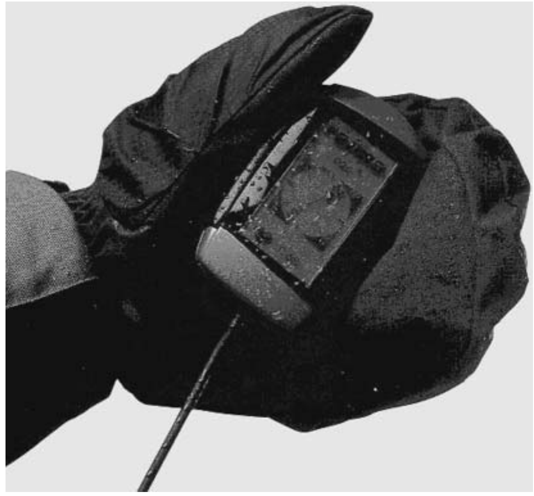

Fig. 3. Yo-Yo user interface.

The hand-held UI module itself is a small unit with a simple graphic display and one-push button. It allows the selection of items from a menu structure. Also, it can be used for entering short text messages. The UI module is connected to the CPU unit via the wire in the winding mechanism. The communication between the CPU and the UI is implemented by using an asynchronous serial communication protocol. Also the power for the hand-held device is carried through the wire.

The unit is suitable for both left- and right-handed people. The operation needs only one hand, and the UI can be activated by squeezing the whole unit. The activation button is only on one side of the device, but due to the way of using it, it is independent of handedness. The interface can also be used in any body posture with thick gloves or mittens on.

The interface allows the user to move between different menus of the graphical user interface on the display by just moving the hand back and forth, and squeezing the module to make a selection. According to the location of the UI module detected by the encoder, the menu changes every three centimeter.

There are two types of menu. If there are

Fig. 4. Menu with many items.

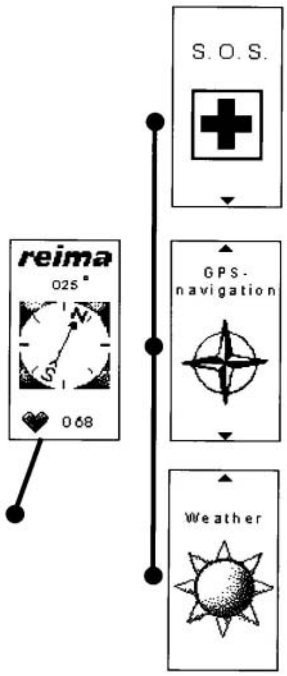

Fig. 5. Picture of menu icon.

several items to choose from, e.g. while entering text or numbers, all items can be shown on the display. In this way the user does not need to remember all possibilities. The selected menu item is highlighted, as we can see in Fig. 4, and moving the device only changes the selection. In the second type of menu, there is only one item shown at a time. The items are icons that fill the whole display. These are used, for instance, while choosing the functions at the first levels of the menu structure. In this case the whole display changes while moving the device back and forth between the menu items. The second types of menus are illustrated in Fig. 5. There are 30 different displays in the user interface, most of which are icons in menus or status displays.

The electronic design of the hand-held unit is shown in Fig. 6. In the design, the Microchip PIC 16F876 microcontroller is used [39]. Its main purpose is to relay image data from the CPU to the display, and to send button status information and compass bearing data to the CPU module. The display component in the UI module is Seiko G1216, which is a 128×64 pixel graphic liquid crystal display (LCD) with integrated LED backlight and a Hitachi controller chip [40]. Ordinary LCD technology is not a good choice for devices that should withstand low temperatures. Other techniques such as Active Matrix Electro Luminescence (AMEL) displays or actively heated LCD-panels would be better. Nevertheless, there were no suitable components available and we had to settle for the LCD module mentioned. Its operation becomes very slow at temperatures below –20 °C. The steel frame of the display module had to be changed to an aluminum frame because the original disturbed the electric

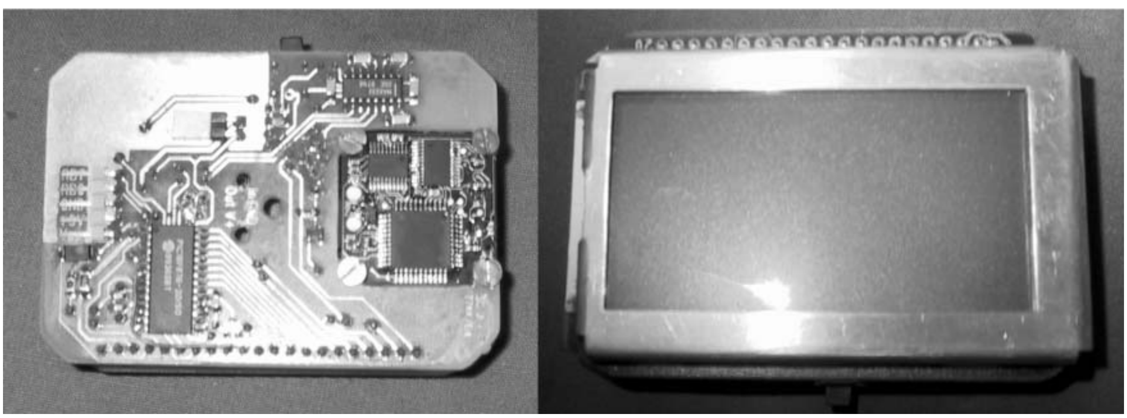

Fig. 6. Display electronics.

compass. The compass is a Suunto Corporation 3-D electric compass module mounted directly on the user interface microcontroller board [41].

7. Performance of the Smart Clothing Prototype

The functionality of the electrical modules was first verified indoors. Every module was first tested alone before the whole system was tested. The prototype was also tested in arctic conditions in Lapland during winter 2000. The behaviour of the suit was ensured with and without the electrical modules. The testing was mainly done by driving a snowmobile, skiing, and walking with snowshoes. During the testing, the performance of the clothing was observed. Attention was paid to the behaviour of the suit especially in demanding tasks such as creeping and stretching. Tests included situations that may cause the sending of an emergency message, e.g. heavy impacts and long-term lying on snow.

7.1. Clothing tests

The suit itself proved to be comfortable to wear, allowing in addition to normal movements more challenging tasks, e.g. plodding through yielding snow. The pocket for snow melting was functional but the sealing should be considered again. When melting snow on a campfire, the pocket had minor leaks. The weight of the electronics in the suit was carried well with the help of the supporting structure. Also the placement of the components was well balanced. The appearance of the suit was like that of on ordinary suit, and users were not able to see any extra bumps caused by the electronics. The numerous cables needed for connecting different electrical components together made the suit more inflexible, especially in stretching tasks. In spite of that, one test person commented that the designed prototype is the best snowmobile-driving suit he has ever used. Other testers were of similar opinion and we may conclude that the placements of the components and clothing design of the system were successful.

7.2. Electrical functionality tests

The alarm system was tested in constructed accident situations, and basically it proved to be operational. All electrical modules were functional, but some connection problems were encountered during testing. In particular, the connector cable of the Yo-Yo was very easily broken.

The requirements set for the suit were mostly achieved. The limiting factor in our design was battery technology and power consumption. The prototype fulfils the requirement for working time. However, the batteries are rather heavy and for that reason new battery technologies (e.g. lithium polymer batteries) should be considered. The method of using the UI proved to be convenient, but the usability was reduced a little when using thick gloves or mittens. This could be enhanced using a smaller display unit, but there was no suitable display for the required temperature range on the commercial market. All components used are not suitable for the desired temperature range. Nevertheless, they are located in a warm place near the body in the supporting structure.

The washing requirement for components that cannot be detached during washing was achieved. However, there was not enough time to make all electrical components washable due to the strict schedule of the project.

7.3. Usability tests

Usability tests for the Yo-Yo interface were made in November 2000 at the University of Tampere. Before the actual tests, the staff of the usability laboratory made a few prototype tests whose purpose was to verify the suitability of the test assignments. 13 students and schoolchildren were selected as test persons, six were women and seven men. Their average age was 20 years. All test subjects were experienced mobile phone users and most of them had been using a personal computer for years.

Tests were divided to four phases. First, test assistants gleaned background information about the test subjects. Secondly, the test assistants introduced the usability laboratory and the test space for the testers. Thirdly, the testers performed the test assignments. In the final phase, the test assistants interviewed the testers in more detail. Three experts participated in supervision of the tests, one of whom acted as a personal assistant for a tester. The other two experts took care in observing and videotaping test situations.

Table 1. Test assignments

1. Switch on Yo-Yo
2. Read a short message
3. Pick up the number of the sender and save it by using a name Pete
4. Call to Pete
5. Find Anne's GPS coordinates
6. Add the coordinates of the place called cottage to the UI

During testing, testers first tried the Yo-Yo by themselves. After that they decided on which hand to use for the UI during the tests. Six assignments that were given to test subjects are introduced in Table 1. The first assignment was supposed to test the intuitiveness of the UI. The second, fourth and fifth assignments tested the basic functions of the UI, e.g. moving between menus and selecting. The third and the sixth assignments tested text-entering features. In the smart clothing prototype, calling was forbidden, but in the usability tests it was evaluated for the sake of later usage. Test conditions were partially defective (e.g. the Yo-Yo was not connected to the chest of the tester as it is in real prototype and testers were not wearing gloves or mittens).

The UI concept is novel as a user interface, although it resembles a traditional Yo-Yo. At first, few test subjects had some difficulties in piecing together the functions of the UI. A very common problem was also the short cable inside the Yo-Yo. In particular, when testers were feeding letters with the UI, the hand easily moved too far away from the body and the length of the cable started to limit the usage. The button of the UI was difficult to use for some testers. The system does not have any feedback other than the actual function, and therefore some test subjects push the button several times wondering why nothing is happening. That is due to the delay in the function of the UI. One important missing feature in this interface is the lack of a general cancellation button. In the alarm sending menu, we have an option to cancel the command, but in text-entering tasks it would be also useful.

The tests revealed several failings of Yo-Yo, though none of these was fatal. The failure only made the UI more complex to use. Therefore, we believe that with proper design, the Yo-Yo interface is a good solution for mobile applications.

8. Electrical Heating

Since building the prototype suit, some further studies have been done to determine the possibilities and usefulness of electrical heating. We have now increased the number of heated elements to cover the whole upper body of the user. The purpose of this study is to find out what influence the additional heating will have on the thermal comfort of users. One aspect is to study the subjective experience of the heating, and also to test generally how people unfamiliar with the electrical equipment will experience the additional electronics incorporated into their clothing. Energy consumption is also monitored. A small-scale prototype for testing the heating possibilities has been developed. The architecture of the heating prototype is explained in the following section.

8.1. Heating system

The platform for the heating system is an ordinary undershirt which is made from thermastat and polyester. Twelve conductive woven carbon fabric panels are fastened to the shirt. Panels are placed on arms, back, stomach, and flanks. Locations for the possible heating places are chosen according to the literature concerning hypothermia situations [42,43] and based on electrical heated commercial diving suits [44]. We have also kept in mind the fact that the circulating blood can spread heat to a wide area of the body when the heating is focused on the big blood vessels [45]. The shirt also contains separate temperature sensors for the temperature measurements, humidity sensors, a power controller board, and a power source board. Two battery packages used in the smart clothing prototype are connected to the power source board of the heating system. A Palm Pilot III can be used as a user interface.

Fabric panels

To achieve the wearability and comfort of an ordinary flexible undershirt, an elastic fabric has been chosen for heating panels. The heating panels are made from conductive woven carbon fabric which is manufactured by Gorix [46]. From the heating fabric we have cut 12 rectangular pieces 185 mm × 50 mm. The size of a panel is chosen so that the resistance value would be 16 Ω. By this decision, we try to keep current consumption within a reasonable range.

The panels have been attached to the shirt using Velcro tape. There are extra tapes in the shirt which allow small variability in the locations of panels, and the placement can be personalised according to the user. Conductive wires for delivering electric current to the panels have been sewn to both ends of the panels. The resistance of a panel changes linearly according to the changing temperature of panels, thus it would also be possible to use these panels as controllers for the heating system. However, we wanted to build our own units for the measurements and the heating system so that we could use them also separately.

Temperature and humidity measurements
The skin temperature of users is measured using the Dallas Semiconductor's one-wire digital temperature sensors [37]. Temperature measurement places have been chosen according to the ISO 9886 standard [47]. The standard deals with the temperature measurement of a body, but we have applied it only in the case of the upper part of a body. Consequently, the sensors can be firmly connected to the shirt and there is no need for any connectors between the trousers and shirt.

Some contacts between the temperature sensors and skin were not tight enough. This can lead to microclimate temperatures being measured instead of true skin temperatures. Therefore, we have added a few straining Velcro tapes to the shirt to obtain more reliable contacts. The sensors used measure temperatures within the accuracy of 0.1°C, which is more accurate than in the prototype suit. This is needed for proper testing. The temperature sensors and three humidity sensors are connected to the measurement unit which executes temperature measurements. The data from the measurements is further transported to the power control unit and also optionally to the Palm Pilot III. The measurement unit also handles the data transfers between the Palm Pilot and the power control unit. The humidity sensors report the humidity values between the user and the outerwear jacket. The measurement unit and the power control unit are fastened to the shirt, which is possible due to their small size and light weight. However, these components are not machine washable and need to be detached during washings. The units are placed on the back of the shirt in two detachable pockets.

Power control and power source
Pulse width modulated power control is provided to the heating system. Pulse widths are calculated from the difference between the temperature measurements and the preset index values. The power control is needed for reducing the power consumption, and preventing overheating of heating fabric. The panels can be controlled separately up to eight loads. If more heating panels are needed, it will be possible to connect loads to the two separate groups. All loads of a group are controlled at the same time, and the maximum pulse ratio will be 50%.

User interface
The user can control the heating system with pen-based Palm Pilot III [48]. The user can manually start and stop heating, start and stop measurements, change the set values for heating, and transport the measured data to the computer for further analysis. It should be noticed that the interface is needed only in this test system. If this kind of heating system is used in actual situations and in commercial smart clothes, it will be preferable to use the Yo-Yo interface for instance.

8.2. Tests and results

To verify the functionality of the heating, the whole heating system has been tested. The tests were made for one person in an outdoor environment, and the purpose was to find out the correct places for the heating panels and collect some subjective information on heating. These preliminary tests were quite promising, and now the user tests are continuing.

The results from the tests are still preliminary. The power consumption is quite high, which means that it is rather complicated to implement electric heating in mobile systems. For example, the smart clothing prototype only has enough battery capacity for 30–40 minutes heating. This means that heating should be allowed only in emergency situations or in situations where battery changing or recharging is possible. However, the electric heating can be used as a temporary heating source. Possible applications are cold prevention while waiting for a bus in wintertime, or preventing cold after doing hard exercise. In those cases, a better solution might be to integrate the heating panels in to the outer jacket instead of in the undershirt. This is obvious for two reasons: first, the undershirt needs to be washed frequently – this means that electronics should be detached quite often and this also reduces the wearability of the shirt; secondly, the panels and electronics are easier to hide in the outer jacket.

9. Discussion and Conclusions

During the smart clothing prototype project a lot of valuable information on real usage, advantages, disadvantages, and problems connected with smart clothing was collected. The sensors and the UI integrate naturally into clothing, giving real advantages to the user. We should not forget that the suit is the first prototype and there are still many minor things that should be done differently.

The integration of the electric components themselves into clothing satisfied our requirements. However, the placement of numerous cables was problematic. To combine the CPU board and the power input boards could be a solution for this. The other solution would be to find more flexible and also more durable cables. In the future, the use of wireless short-range communication instead of serial cables may also improve the situation. The cold durability of the components satisfied us, but the UI module using LCD display begins to slow down below minus 10°C. Thus, it should be replaced by a more suitable display technique in the future.

The electric heating study is still continuing. The basic problem is the power consumption, because the batteries used in the smart clothing prototype can only be used about half an hour for heating. This is obviously too little for survival suits.

The Smart Clothing project was one of the few technical research projects in Finland that have been reported widely in public. It has been seen on all Finnish TV channels and on several European TV channels, including the BBC. In addition, the project has been reported on about ten radio stations and in several newspapers. From the promising test results and the positive publicity on the project, we are convinced that there is an actual need for smart clothing. Future plans for expanding the target group include providing smart clothes as professional tools, e.g. for firemen. Later, the smart clothing concept could be used to provide help for special groups such as the elderly, disabled people and children.

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