Smart Clothing for the Arctic Environment

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Abstract

New fiber and textile materials and miniaturized electronic components make it possible to create truly usable smart clothes. These intelligent clothes are worn like ordinary clothing providing help in various situations according to the designed application. This paper describes the design and implementation of a survival smart clothing prototype for the arctic environment. Concept development, electrical design, non-electrical features, textile material selection, and clothing design are discussed. Communication and positioning aids have been provided to the suit's user. Several human and the environment measurements decide whether an emergency message should be sent. The functionality of the suit has been tested in the arctic environment.

1. Introduction

Smart clothing combining wireless communication and wearable computing has become a potential alternative for a wide range of personal applications, including safety and entertainment [1]. We see the smart clothing as ordinary clothing, augmented with electrical or non-electrical components and intelligent fabrics. Based on these, we get an intelligent garment, which can better fulfil its primary function as clothing and also give some added value to the user.

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

Smart garments are intelligent products, which provide the platforms to develop new innovative applications. Clothing may act as a communication medium, information content platform, or as an interface for the future ubiquitous computing devices. Smart clothing can promote safety with the help of different alarming, positioning, and sensor systems. Clothing may also provide working aid, e.g. for doctors performing physiological measurement and data collection tasks or for maintenance workers by offering help with communication tasks.

In Section 2 we discuss the project background. In Section 3 the requirements for the system are given. Based on those requirements we give a description of the design and implementation of a smart clothing prototype in Section 4. Clothing design, electrical design, material selection, and washing tests are discussed. The testing environment, test methods, and main results are presented in Section 5. Section 6 is the concluding section.

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1.1 Related work

During the last ten years, there have been a number of research projects on wearable technologies at universities, including Massachusetts Institute of Technology, Carnegie Mellon University, Georgia Tech, and Tampere University of Technology. However, these have strongly concentrated on wearable computers and their applications. These computers are rather carried than worn and they are intended for every day life rather than for a particular application.

The wearable sensor jacket by Philips takes wearability properties into consideration [2]. Our approach is similar. However, our prototype is developed for a very specific application. The full-scale smart clothing prototype that has been constructed and also tested, is to our knowledge the first one in the world. The work, which started at Reima-Tutta will continue at Clothing+, which is a research center for wearable technologies [3]. Their intention is to develop commercial smart clothing products in the near future.

2. Project background

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

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

There were three major reasons to choose a survival suit for snowmobile users as the target application. First, snowmobile suits provide a good platform for placing additional components into clothing due to suit's high volume and weight. Second, the application area has evident dangers and problems, which need to be solved. Third, an obvious reason was Reima-Tutta, the company behind the project that already produces clothing for the arctic conditions.

3. Methods

The work started with the determination of the user requirements. Our assumptions were that the user knows basic survival skills, knows his own capacity, has the basic first aid skills, and can fix common mechanical failures of snowmobiles. The next step was to find out the problems that may arise during the use of the garment in defined conditions. The prototype is designed to fulfil these requirements while being as good and functional to wear as an ordinary snowmobile suit.

We interviewed frontier guards, insurance companies, and professional snowmobile drivers to chart problems concerning snowmobile users. This survey showed that there are seven general problems that users will meet in the field. The problems were: 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. The goal was that the suit must solve in some way all these seven problems.

3.1. Clothing design requirements

The areas that affect clothing design in smart clothing are illustrated in Figure 1. The circles show the areas that have an impact to the product. These areas are clothing, technology, and the user. In the center of the model is the product itself, which is designed under pressures from the demands and needs that the circles around it have but also with the means and possibilities the circles can offer.

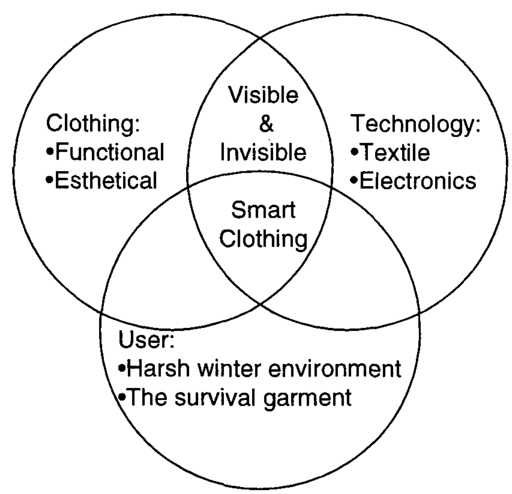

Figure 1. Modeling connections between clothing, technology, and a user.

The technology circle includes new materials and functional features that are included into the garment. *The* *clothing circle* consists of functional and esthetical aspects, which are always present in clothing, only emphasis can be different [4]. *The user circle* includes those aspects that rise from the user's needs under the environmental pressure, which in this case is the harsh arctic winter environment.

Words *visible and invisible* bring out the fact that there is always a tradeoff between the appearance of the clothing and the technology in smart clothing. It is possible to fade out electrical components into the clothing leaving only a hint of them to appear. On the other hand, the garment may be enslaved by electronics and thus loose its function as clothing and become a platform and a surface for the technology.

Designing a garment for the harsh winter environment has its own limitations and demands. Integrating electrical features as a part of the clothing complicates the design of a functional and comfortable garment. The added electronics also guides the design of the outer appearance.

The level of fading of the electrical features into the garment was affected by biomimetics that is an innovation of the textile technology [5]. Flexible, insect-like organisms and designs extracted from nature gave the means to do the fading process. According to this process the electrical features become invisible, but the design still gives a hint of something new in the appearance of the survival garment.

3.2. System requirements

The basic requirement for the mobile computing system is portability, which means small size, low weight, and low power consumption [6]. Therefore, a limit for extra weight was set. Usually, 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 demanded that the suit should work 24 hours before recharging, therefore to reach for the minimum power consumption on each device had to guide the electronics and software design.

The user interface (UI) was very challenging to design because of the operating environment, the mobility requirement, and the user-friendliness requirement. UI should enable selection from menus and basic text entering tasks. 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. Second, the interface should be functional for both left and right handed persons.

The arctic conditions set demanding requirements for the electronics, such as a high range of operating temperatures and changing humidity. Components are chosen to endure temperatures from –20°C to +50°C. The components that are integrated into the textile's structure need to be machine washable. The components fastened to the supporting structure will be detached during the washing and therefore do not need to endure submersing. All the components including non-electrical parts should be cushioned and covered so that wearability of the clothes still remains.

Electronic components should be split into smaller units and spread out over a large area on the user's upper body to gain on flexibility and to lose unnecessary strain on any single part of the body [7]. By placing the heavy battery-units on the sides by the kidneys, the battery weight could be brought close to the body as well as the batteries could be kept warm with natural body temperature. The electronics however, is itself a source of heat which may affect body temperature balance. Perspiration means loss of energy and wet clothes, which decreases the survival time in cold weather.

4. Results

The design results are given in this section. The section is organized as follows. First, general description is given including problem solving methods and non-electrical features. Second, the clothing and encasing design are described. After that we give a description on each electrical module in the suit. The rest of the chapter discusses textile selection and washing tests that were made to the suit.

4.1. General description

The suit consists of a two-piece underwear, supporting vest, and actual snowmobile jacket and trousers. The garment is capable of giving information about wearer's health, location, and movements. With several integrated sensors it is possible to monitor user's condition and position. If the user encounters an accident or another abnormal situation, the suit will inform an emergency office or use another preselected phone number via the Short Message Service (SMS) of the Global System for Mobile communication (GSM). The user can also send the emergency message himself. The message contains the current coordinates of the user's position and the data from the user and the environment measurements. The coordinates are acquired using the Global Positioning System (GPS).

Problem solving. Getting lost is solved by using GPS and an electronic compass that will help the user to navigate towards the nearest city or road. It is also possible to ask the location of another suit. Encountered accidents and health problems are solved with same kind of methods. In this situation information gathered from several sensors may also cause an automated emergency message sending.

Problems caused by unexpected weather conditions are solved with SMS weather service, which we have in Finland. The service responds to SMS request and tells the weather forecast in the asked area. Non-electrical features solve the lack of equipment. Hedging against cold is done with proper material solutions and with electrical and chemical heating solutions.

Alarm messages are divided into three categories. Automated emergency messages will be sent if data from sensors is abnormal and the user does not react to light and tone impulses. If the alarming is false, the user can prevent the sending during 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 relieve the user's efforts in message sending in a case of an injury. The user only has to select the correct menu and click the button. Other kinds of alarm messages are not allowed to be sent.

Non-electrical features. The smart clothing prototype includes several added non-electrical features for supporting the user in occurred accidents or for enhancing the clothing's own functions. These include a transparent map pocket in the front of the left thigh. A special pocket that can be used for melting snow is added in 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 off from a hole in the ice. Waterproof and windproof hypothermia bag is also added into the back pocket of the jacket. The bag is large enough for providing shelter for the user. Finally, the suit includes a special easy access pocket designed for a mobile phone.

4.2. Clothing design

Encasings design. The encasings are designed to follow the shapes of the moving body to decrease the inconvenience caused by hard objects against the body. Each shape has its own spot on the body where it fits without restricting the mobile user. The encased units will also act as a protective harness by transferring an impact away from vital organs and spreading it out. To maintain proper ventilation and cooling around the heat-producing electronics, the devices are encased in plastic shells and a layer of open-cell plastic foam. The foam acts like a spring suspending impacts and adding convenience. With every impact from natural movements the foam pumps air through its cells keeping perspiration low. Since the foam ventilates the back continually, a backpack will not cause a wet back.

The supporting vest. In order to maintain the look of an ordinary piece clothing, good wearability and comfort, the electronics were not sewn into the garment shell. A supporting structure is constructed between the coating and the lining to carry the weight of the devices. Thereby, the mass of the electronics does not affect the posture of the garment. The supporting structure brings the mass against the user's body leaving the outer shell free to move and drape like any clothing. The supporting structure, illustrated in Figure 2, 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. The supporting structure can be detached during washing of the jacket.

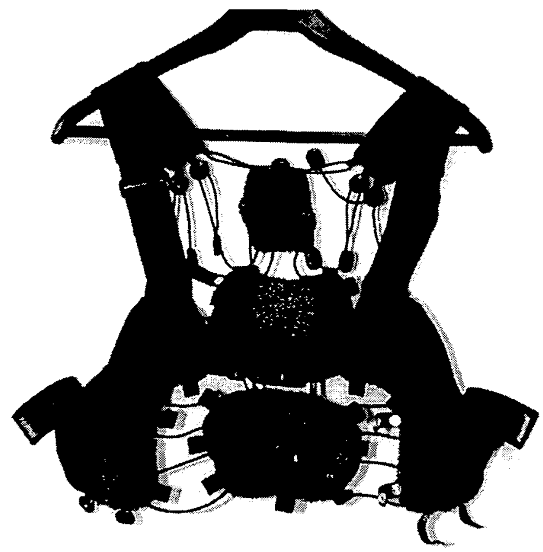

Figure 2. The supporting vest.

The jacket. The component integration into the jacket is done by keeping the jacket as comfortable as possible and applying as many standard structural solutions from clothing manufacturing as possible.

The structure for storing the UI device is made by using overlapping situated fabric forms, where the UI could be pulled out and put back easily. The idea of biomimetics is also considered. The cuttings of the jacket are formed to cover the extra bumps caused by the electronics, especially on the backside. Additional "biomimetical touch" was achieved with reflective prints instead of using more ordinary reflective stripes or fabrics.

Transferring power and data between shell, electronics and underwear is done by taping liner material cable tunnels onto the inner surface of the garment. The wiring runs along seams and wires are carefully placed in order not to restrict movement or stretch. The wires and connectors are waterproof and can be washed with the jacket. Designed suit is illustrated in Figure 3.

Figure 3. The smart clothing prototype

The underwear. The smart clothing concept also includes a two-piece underwear, where the heart rate measurement equipment are fastened. The electrodes for pulse measurements are made of metal glad aramid fibers. Another two features in the underwear are related to the heat balance of the body. A thermal equalizer is made of Outlast phase changing material. In addition to this there are electronically heated conductive woven fabric panels on wrists. If necessary, the panels warm up the circulating blood increasing the activity time of the user. All added features are integrated within the structures of the clothing to make the underwear comfortable to wear and to hide the additional components from the eye.

4.3. Electrical design

The prototype consists of four functional segments: communication, navigation, 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. 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 into the supporting vest. The architecture of the prototype is illustrated in Figure 4.

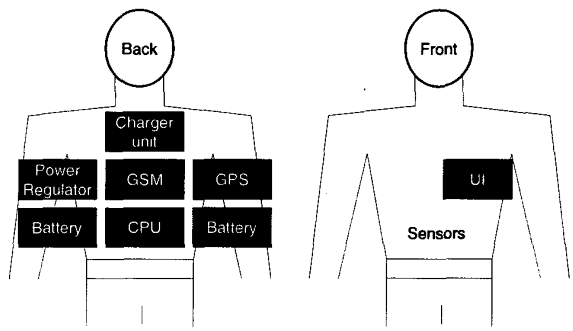

Figure 4. Architecture of the prototype.

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. Toshiba's NiMH cylindrical battery cells are divided into two five-cell units having nominal voltage of 12 V and total capacity of 4000 mAh [8]. Batteries are connected to the charger unit and the supply unit. The batteries can also be charged from electrical network via a proper adapter. Batteries are the heaviest parts of the system weighting 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 inputted to CPU unit that forwards the right voltages to the correct components.

GSM. GSM is used for automatic communication after an occurred accident in case of injury. The communication can also be utilised by the user if a technical failure or minor health problems are encountered. In addition, a service for weather forecasts is available in Finland. Because the prototype is tested and developed in Finland the chosen communication channel was apparent, but the solution is location and country dependent. The used GSM module is Siemens's M20T, which is easy to connect to the CPU unit using a serial cable [9]. There are also options for a speaker and a microphone in the module but in the prototype only the short message service was decided to use. With this decision we try to prevent needless use of phone and power wasting.

GPS. The Conexant's Jupiter GPS module is connected to the system for positioning and navigation tasks [10]. An active antenna for GPS is placed onto the shoulder of the suit, assuring that the satellite signal can reach the antenna for most of the time. The accuracy of the system is approximately 10 m. GPS card and its connector card are located in the same capsulate. 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 travelled route.

CPU. The prototype has two microcontroller boards designed at Tampere University of Technology. The CPU board is the heart of the system, and all other components are connected to it.

The CPU board has a Hitachi H8/3003 16-bit microcontroller [11]. It runs at 16 MHz and has 1 MB external RAM and 512 kB external Flash memory. 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 [12]. The memory mapping of the CPU is identical to the evaluation board.

Since the H8/3003 has only two firmware serial communication ports and the GSM, GPS, UI, and the 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 [13]. The other serial communication port of the processor was reserved for software development.

User interface. The main device of the user interface is called a *Yo-Yo* interface. It is a small unit with a display allowing selection and text entering tasks. The UI module is connected to the CPU unit. The winding mechanism of the Yo-Yo and the optical rotation encoder is embedded into the clothing. The interface allows the user to change between different menus of the graphical user interface on the display by just moving the hand back and fort and squeezing the module to make a selection. According to the location of the UI module detected by the encoder the menu changes in every 3 cm. There are 30 different menus and submenus in the user interface. The user interface module is illustrated in Figure 5. Benefits of this kind of user interface are the suitability for both left and right handed persons and the possibility to use the module by one hand and in any body position. The interface module also embeds an electrical compass. In addition to the Yo-Yo device, the suit's user interface can give audio and visual alarms to the user. There is a small loudspeaker situated at the suit's collar and a white light emitting diode (LED) in the sleeve of the jacket.

The main purpose of the microcontroller in the user interface module (Microchip PIC 16F876) is to relay image data from the CPU to the display [14]. The display component in the UI module is Seiko G1216, which is a 128 x 64 pixel graphic liquid crystal display (LCD) with integrated LED backlight and a Hitachi controller chip [15]. In addition to receiving data, the UI module also sends data back to the CPU. Sent data includes button status information and compass bearing data from the Suunto Corporation 3-D electric compass module mounted on the user interface microcontroller-board [16].

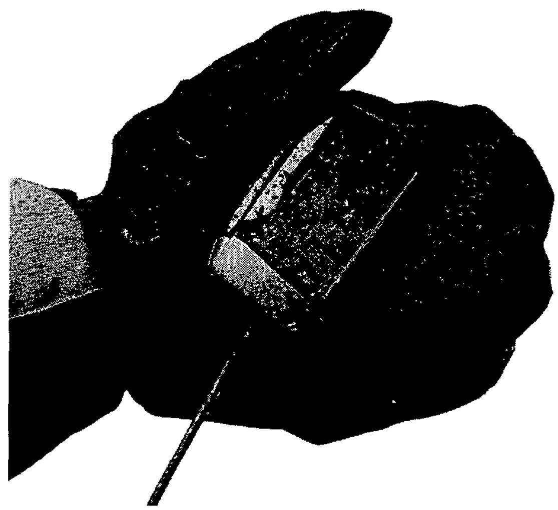

Figure 5. The Yo-Yo user interface.

Sensors. Monitoring of the user and the environment is done for helping 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 [17]. Sensors are connected to the comparator, which generates an external interrupt pulse if acceleration exceeds the pre-set level. All acceleration sensors are placed into 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.

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 is the posture of the user [18]. 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 [19], 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 low-frequency magnetic field.

One-wire digital temperature sensors measure microclimate temperatures inside the supporting vest and in the jacket's cover textile. Sensors used are DS1820 sensors manufactured by Dallas Semiconductor [20]. Implementing the 1-wire interface with one I/O pin is possible, but because that would have significantly increased the complexity of the software the 1-wire sensors were connected to the serial multiplexer through a serial 1-wire line driver (Dallas DS2480) [21]. A 1-wire EEPROM chip for storing user specific data was also added to the 1-wire bus.

Heating. Electrical heating is implemented using the conductive woven carbon fabric panels in underwear's wrists. The problem is that heating needs a great deal of energy and batteries may quickly run down. To reduce the power consumption the heating is allowed only after alarming. The constant heating may also passivate the user and this way affect user's chance to survive.

4.4. Selection of textile materials

Underwear. The two-piece underwear was made up from warp knitted net fabric. The yarns were manufactured of tetra-channel polyester fibers. Pieces of phase change material were sewn inside the shirt and the pants to regulate the body temperature and thus improve the thermophysical wearing comfort. Flexible conductive yarns made from metal clad aramid fibers were used for signal conductors of the heart rate monitor. The same yarn quilted to the shirt was used as electrodes. Flexible heating system was incorporated into the cuffs of the shirt. The heating elements are carbon conductive woven fabric. Cables run from both heating pads along the seams. The heating system was tested in laboratory and in practice. The temperature was measured on the surface of the carbon fabric in the laboratory conditions. The resistivity changes linearly as a response to temperature change (Figure 6), and thus it could also be used as a temperature sensor.

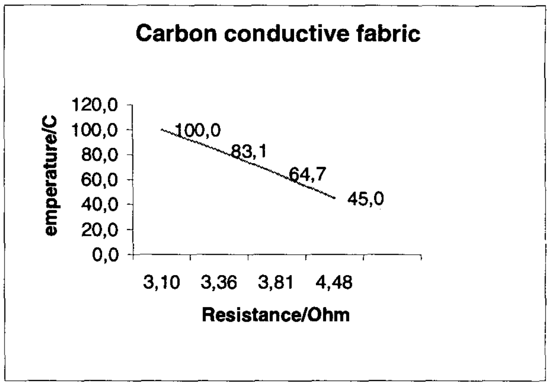

Figure 6. The linear change in resistance as a response to the temperature change.

Jacket and trousers. The outerwear material is composed of two PTFE-laminated polyamide fabrics, mass per unit areas 230 g/m^2 and 140 g/m^2. Adequate mechanical properties such as abrasion resistance and bursting strength are essential. Before selection several materials were tested. Windproofness, water vapor permeability and water penetration resistance were also measured. Abrasion resistance was tested according to standard ASTM D 3886 with Stoll device, in which sandpaper is used as a friction surface [22]. Adamel Lhomargy device is used to measure the bursting strength, where the pressure comes under the fabric. Air permeability was tested according to standard EN ISO 9237 [23], Gore´s cup method was used to test water vapour permeability and water penetration resistance was tested according to EN 20811 [24]. Both materials were breathable and windproof. The test results are given in a table 1.

Table 1. The properties of outerwear materials.

Property	Material 1	Material 2
Mass per unit area (g/m^2)	140	230
Abrasion resistance (turns)	2 767	4 833
Bursting strength (kPa)	1 464	2 143
Water vapour permeability (g/m^{2}24h)	3 952	3 718
Hydrostatic head (mmH_2O)	10 000	10 000

The removable snow-melting pocket is made from Aramid and aluminum tape. The melted snow was analyzed and found drinkable. The map pocket with transparent window is made of 100 % polyester film. The film was tested against freezing (-20°C) and the results were good. The film remained unchanged.

Reflective paste has been used to printings in the suit. The printed fabric has been tested: determination of colorfastness to xenon arc light (EN 2015-B02) [25], determination of colorfastness to rubbing (EN ISO 105-X12) [26] dry and wet. From both tests the printed material got good results. Martindale rubbing test (EN ISO 12947) was also made and after 35 000 turns the material was still reflective [27].

4.5. Washing tests

The main focus after usual washing tests of clothes was to study the function of electronics and other special components connected to the smart clothing. Circuit boards, cables, a sound source, temperature sensors, and components made from metal clad aramid fibres and conductive woven carbon fabrics were studied. Washing tests were made furthermore for reflective material and film polyester used in the map pocket. Also dry cleaning tests, perspiration durability and seawater durability were made for circuit boards.

The washing tests for circuit boards and cables were made according to standard ISO 6330 15 times both in 40° C and 60° C [28]. Some circuit boards were coated with epoxy resin. The circuit boards and cables were inside cloth bags during the washings. All the circuit boards were still operational and cables were undamaged after 15 washing tests. The long-term problem could be the untimely aging of these components influenced by washing.

The washing tests for temperature sensors, a sound source, and components made from metal clad aramid fibers and carbon conductive woven fabric were made 10 times according to standard ISO 6330 in 40° C [28]. After washing tests all these components were functional.

Reflective material and film polyester material were washed 10 times according to standard ISO 6330 in 40° C [28]. After washings both materials were undamaged but the reflective effect was a little decreased.

Dry cleaning tests were made five times for circuit boards in laundry by normal dry cleaning process with perchloretylene. Circuit boards were inside cloth bags during the tests. All the circuit boards were operational after dry cleaning processes.

Perspiration durability tests and seawater durability tests were made for circuit boards applying standards SFS-EN ISO 105-E04 [29] and SFS-EN ISO 105-E02 [30] respectively. There were operation breaks during the tests, when circuit boards contacted to "perspiration solution" or to salt water but when dried after the tests they were functional again.

5. Performance of the suit

The functionality of the electrical modules was verified first indoors. Every module was first tested alone before whole system testing. The prototype was also tested in arctic conditions in Lapland during the winter 2000. The behavior 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 behavior of the suit specially in demanding tasks such as creeping and craning. Tests included situations that may cause an emergency message sendings, e.g. heavy impacts and long-term lying on snow.

The suit alone showed to be comfortable to wear allowing in addition to normal movements also more challenging tasks e.g. slogging in deceptive snow. The pocket for snow melting was functional but the sealing should be considered again. When melting the snow on a campfire, the pocket had minor leaks. The weight of the electronics in the suit was carried well with help of the supporting structure. Also the placement of the components was well balanced. The appearance of the suit was like ordinary suit and the users were not able to see any extra bumps caused by the electronics. The numerous cables needed to connect different electrical components together made the suit more inflexible, especially in stretching tasks.

The alarming system was tested in framed accident situations and basically it showed to be operational. All electrical modules were functional but some connectivity problems were encountered during the testing. Especially, the connector cable of the Yo-Yo was very sensitive to get broken.

The placed requirements for the suit were mostly achieved. The limiting factor in our design was battery technology and power consumption. The prototype fulfills 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 UI showed to be convenient to use, but with thick gloves on the module was difficult to use. This could be enhanced with smaller display unit, but there was not suitable display for required temperature range in commercial market. All components used are not suitable for the desired temperature range. Nevertheless, they are located in a warm place near body in the supporting structure.

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

6. Discussion and conclusions

During the project a lot of valuable information from real usage, advantages, disadvantages, and problems encountering 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 the numerous cables was problematic. To combine the CPU board and the power input boards could be the solution for this. The other solution would be to find out 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.

Smart Clothing project was one of the very 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 BBC. In addition, the project has been reported on about ten radio stations, and in several newspapers. Trough the promising test results and the positive publicity of 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 on, 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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