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THE MODELING OF ADAPATIVE POSTURE ADVISORY SYSTEM FOR DECUBITUS PREVENTION DURING AIR TRAVEL

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ABSTRACT
The design process of any technical system is based on well elaborated procedures, which leads step by step, from concept to the final product. For industrial product, such as adaptive advisory systems, a combination of multiple technology such as electronic and computer science is involved. There are certain creative and innovative operations and activities leading to the final product. Sitting is the most common activity during air travel. Decubitus is widely recognized as serious complication for a person with spinal cord injury. Motor paralyses affect a person's ability to respond unconsciously to potential noxious stimuli. Thus, decubitus affect the quality of life of spinal cord injury patient. For the spinal cord injury patient who travels with long haul flight, which is more than 5 hours, the decubitus risk will increase. In this paper the conceptual design process of adaptive posture advisory systems for decubitus prevention during air travel is presented as a set of models, which make the design of these systems possible by integrating different technologies and reflecting themselves on the conceptual design process. Apart from that, they represent the example of transformation of the design process into a form suitable for realization by combination of different technologies.

KEY WORDS
Design process, modeling, debicutus ulcer, spinal cord injury, and adaptive posture advisory system

1. Introduction

Design is the act of formalizing an idea or concept into tangible information. It is distinct from making or building. Taking the concept for an artifact to the point begins just before the process of converting it into a physical form [1]. The design process of industrial systems is based on the transformation of lower level information into a higher level. The knowledge is expanded by using new information. The new information process can be represented by suitable models. The modeling method becomes the language of designer and models themselves to form the knowledge base. The models are useful in the knowledge normalization and decision making process.

The design process, which might be called the synthesis of a technical system, consists of several stages and it is defined by VDI 2221 recommendations. VDI 2221 [2] is a guideline which has attempted to encapsulate the available methodologies in to a working framework. In common with other systematic prescription, it suggest that engineering design goes through four sequence phases, such as task description, conceptual design, embodiment design, detailing in design. Task description is involved the correction of information about requirements and constraints, followed by the generation and subsequent elaboration of detailed specifications. Conceptual design is the development of general ideas or concepts to use to fulfill the requirement specifications. Embodiment design is the stage that selected concepts are successively developed and refined. Lastly, detail design is where the arrangement, form, dimensions and surface properties of all parts are finally laid downp; the materials is specified, the product feasibility is rechecked and all production documentation is produced [3].

Design analysis is performed either on existing designs or on new ones, produced by the syntheses and makes possible design optimization by using numerical and/or experimental methods (stress, vibration, reliability, noise, etc.). Moreover, design analysis provides data for the knowledge database necessary for further development of the design process and products. In specialized fields of mechanical engineering some of the design stages and operations are not of the same priority and will not be realized in the same way as others. This is so because of unequal development and sophistication of individual stage. Some have attained very high levels, involving specific (and rare) knowledge. The requirement is that the specific details are highlighted and put in a proper place within the general procedure of the design process [4].

In this paper, we present the design modeling of adaptive posture advisory system (PAS) for aircraft passenger with spinal cord injury. The aim of the developed system is to reduce the decubitus ulcer risk for people with spinal cord injury.

The paper is organized as follows: Section 2 describes the relationship between spinal cord injury patient and air travel. Section 3 describes the architecture of adaptive posture advisory system. Concept development details follow in Section 4 and final design is presented in Section 5. Section 6 describes the experimental setup. The paper is concluded in Section 7.

2. Decubitus Ulcer and Air Travel

Air travel is becoming increasingly more accessible to people both through the availability of cheap flights and because the airlines are now able to cater for individuals of all ages and disabilities. Health problems may arise due to anxiety and unfamiliarity with airport departure procedures prior to flying, whilst during the flight, problems may arise as a result of the food served on board, differences in the environmental conditions inside the cabin (pressure, ventilation, relative humidity, noise and vibration), the risk of cross-infection from fellow passengers, seat position, posture adopted and duration of the flight. Travel by air, especially long distance, is not a natural activity for human. Many people experience some degree of physiological and psychological discomfort and even stress during flying. Excessive stress may cause passenger to become aggressive, over-reaction, and even endanger the passenger's health. A number of health problems can affect flying passengers.

Pressure damage from long hour sitting is one of the common healthcare problems and affects all age groups. For spinal cord injury (SCI) patient that spends a long hour in sitting will increases the risks of decubitus ulcer. SCI patient are not able to sense the environment with the parts of the body that are cut off from the nervous system. Signals as pain are elementary to prevent the human body to prevent from damage. 85% of the people with SCI experience the damage that are directly related to the problem of unable to sense the signals that alert the human body for pain [5]. By not sensing pain, there is an increased risk on decubitus. The aim of the present paper is twofold. First, it sets out to describe the nature of comfort and discomfort during sitting as well as long hours sitting problems. Secondly, it describes an intelligent adaptive advisory system that is embedded into the economy class aircraft seat.

3. Architecture of Adaptive Posture Advisory System

Figure 1 shows the architecture of adaptive posture advisory system for aircraft seat. The passenger seat will be embedded with sensors and actuators. The sensor is designed to detect the passenger condition such as physiology, pressure, movement and posture. The output from sensors will be input to central processor and database. The central processor is the core component of the system where it is used to mediate between sensors and actuators. The algorithms for the system is to: (1) advise passenger sitting position and support adaptively; (2) provide better sitting support and propose solution according to passenger's sitting condition. The database is used to record sitting behavior and condition of passenger. The outputs from the system are the actuators. The actuators will change the seat condition such as shape, softness, and contour. For example, when passenger feels discomfort during sleeping, he/she will change the sitting posture frequently; the inference engine will get the preferred seat condition list, select best seat condition according to passenger current sitting posture and automatically change the seat condition to reduce passenger's discomfort feeling.

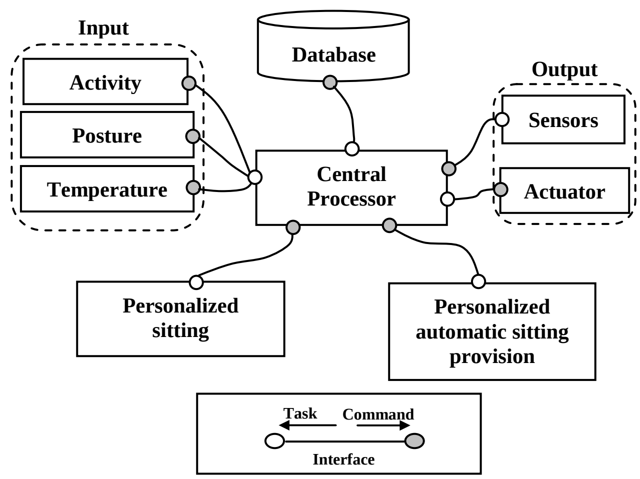

Figure 1. Architecture for the adaptive posture advisory system

4. Conceptual Development Modeling

The goal of the project is to decrease the risk on seating acquired pressure ulcers. The concept that is chosen for further development focuses on postural feedback that alerts the user for peak pressures and instructs how to avoid these. During the development of the concept there is a strong focus on privacy, intimacy, and intuition. The development of the prototype exists out of two elements. One element is the input the other element to the output. The input measures different physiological states and the result of the measurement is translated into an output. The output will be created with multiple actuators. For the development of both the input as the output two areas are important to explore. One area is the development of tactile feedback and the second area is the integration of technology into clothing. Figure 2 shows the concept requirement model.

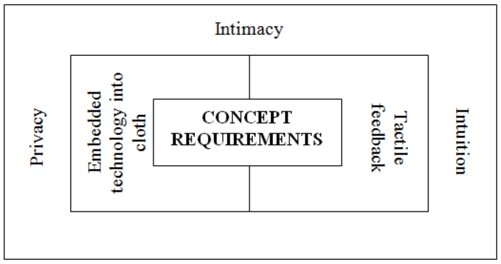

Figure 2.The concept requirements model

4.1 Concept 1: Embedded Technology of Clothing

The development of smart textiles is at a starting point with high expectations from different markets such as leisure, sport, and healthcare. Projects as EASYTEX and Clothing Area Network [6] explore scenarios of the future that inspire for new applications. Another example is TNO that show the possibilities of physiological measurements with the presentation of the intelligent firefighters garment.

For this design concept, the risk on decubitus can be monitor based on the pressure, temperature, and humidity of the skin. For people with SCI, the lack of sensory input disables the body to react on influences from the environment. With the implementation of sensors it will be possible to 'sense' the environment and react on it. The shape of the body influences the pressure measurement and it would be much better to shape the measurement around the human tissue. With the integration of sensors in textile constructions it will be possible to design clothing that actively monitors the body and the interaction with the environment. With the information it will also be possible to protect the body from the environment.

To integrate electronic components into clothing the components should be designed in a functional, unobtrusive, robust, small and inexpensive way. Especially the requirement unobtrusive is important because a physical obtrusive design (rough, sharp) could improve the risk on pressure sores. The sensor must be designed in a way that its physical condition doesn't have a negative effect on pressure, shear or other physiological conditions of SCI passenger.

From different studies and experiments several technological textile solutions are designed to measure physiological elements. The textile spacer is designed to measure the pressure on a surface. Two conductive layers separated by a spacer (textile with a physical resistance) are connected when the pressure on the surface is higher than the physical resistance of the spacer. Another sensor that is created with textiles is a moisture sensor. The sensor is woven with conductive yarn and exists out of three layers. The two outer yarns are connected with a power supply and the middle layer is a 'normal' yarn. When the humidity increases the resistance of the middle layer decreases and this difference is translated into humidity. A third sensor that is interesting for decubitus prevention is a hybrid textile that measures temperature. The voltage drop of a copper wire is measured and the extracted resistance relates to the temperature. The sensors in combination with chips create smart textiles. Besides, the integration of technology into fabrics, it is also important to be aware of different needs and restrictions related to clothing: aesthetics, functionality, and availability. Figure 3 shows the conceptual design model for embedded technology of clothing.

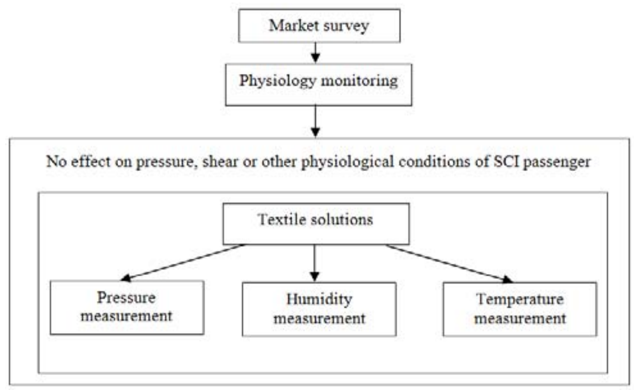

Figure 3. Conceptual design model of embedded technology for clothing

4.2 Concept 2: Tactile feedback

Tactile feedback is a design element that is commonly used for human-computer interfaces. It is one of the many interaction mediums with specific properties that fit the terms natural and private feedback. Because artificial touch is not commonly integrated in daily life (except the vibration of mobile phone) the designed feedback needs to be intuitive or learned by the user. A study about vibrotactile feedback [7] identifies two types of vibro-feedback; impulse and continuous feedback. Impulse refers to ballistic interaction as knocking. Continuous feedback refers to contact over a longer period of time. Where impulse feedback could be used to link to information it is interesting to find out how vibration feedback itself can contain information, information containing feedback. Figure 4 shows the comparison of the feedback and information for vibrotactile feedback.

Tactile feedback in human computer interaction often is an interaction between a sensor, actuator, and the user. Both sensing as actuating, from both the system as the user, take place at the same area. In the case of a person with a SCI the area of sensing and actuating are interconnected. For this project an interaction partner (tactile feedback) is proposed to replace the real interaction partner (seating surface). In comparison with the examples from the study this set up make it difficult for the user to explore the interaction partner.

	Feedback which links to information	Information containing feedback
Direct feedback (on body)	Vibration, temperature	Vibration pattern
Indirect feedback (outside body)	Audio, visual	Visual, audio
	Impulse feedback	***Continuous feedback***

Figure 4. Feedback and information

4.2.1 Multi-sensory interaction model

4.2.1.1 User

When designing for people with a spinal cord injury it is necessary to focus on possibilities but also on possible limitations. It is also important to focus on privacy issues because the feedback includes information about the body (information that is normally processed within the body). Another important aspect is the level of attention, does the user need to pay attention to the device all the time or only at specific moments. During the concept development three types of feedback are defined, there are support, demand, and play (Figure 5). Support feedback naturally supports the user with feedback. This method can be compared with training-wheels. Demand feedback forces the user to obey to the information that is given. An example of this type of feedback is an airbag. The third type of playful feedback.

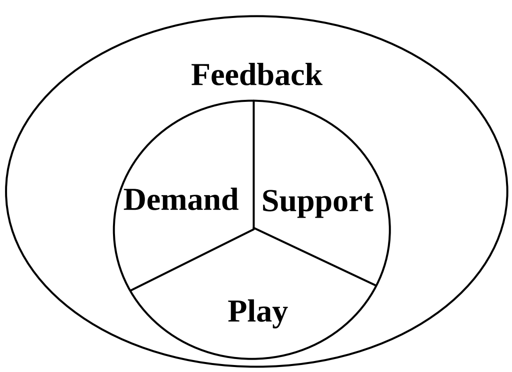

Figure 5. Conceptual model for feedback

4.2.1.2 Environment

The model of multi-sensory interaction is mostly used for virtual environments. Usually a CAD model functions as environment. For people with SCI the environment is the place where the body (without the ability to sense) interacts with the world (in this case the wheelchair). An interesting factor of this environment is the level of irritation. As described in previous chapters different factors influence the irritation. For this concept it is important to detect peak pressures.

4.2.1.3 Physical Interface

The physical interface accepts input from and provides output to the user for the sensory modalities. With a pressure measurement device the interaction of the body with the wheelchair is monitored. Force Sensing Array (FSA) is a system that is normally used for the selection of decubitus prevention cushions. With the system it is possible to visualize pressure distribution. The input that is gathered for the supporting feedback is peak pressures. When a peak pressure is located the system translates this into supporting feedback to guide the user in a position that avoids peak pressures.

Because the user cannot sense with the part of the body where the irritation takes place this information is translated by multiple actuators. The actuators communicate with different tactile patterns to inform the user about harmful situations. With the information the user is able to avoid these. The modality that is selected is multiple vibration units that are located on the upper part of the body.

4.2.1.4 Interaction Model

With the interaction model the relation between user and environment (wheelchair) is defined. The user interacts with the prevention device within an environment with different types of information. This information is communicated over different mediums (audio, visual, and tactile). The physical interface interferes (with only tactile information) the existing information to guide the user to a new posture. The feedback is created with information from a measurement device. This measurement device detects peak pressures and translates this information into tactile direction patterns that instruct the user to change his posture. Because the use of tactile feedback is at its starting phase different experimental models are developed. From different experiments, the method will be selected to communicate with the information from the measurement device.

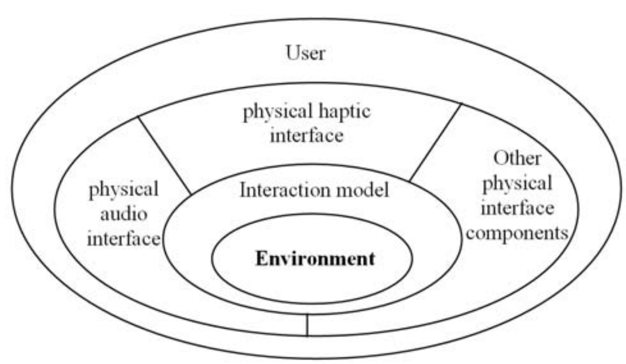

Figure 6. Multi-sensory interaction concept model (adopted from [5])

4.2.2 Tactile feedback experimental model

Two tactile models are designed to test the influence of distance and frequency for the perception of tactile feedback.

Model A is a patch with a diameter of 10cm that contains 13 vibrators. The distance between the vibrator is +/- 2cm. Model A explored the neck, back, arm and belly. The patch is designed as dynamic vibration unit. The patch is programmed with 5 different patterns. When it is possible to identify 5 different patterns in theory two patches are able to communicate 25 messages. Figure 7 shows the developed model A.

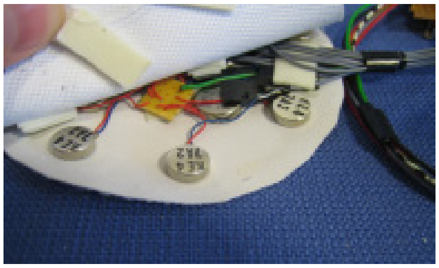

Figure 7. Model A

Model B is a belt of 100cm that contains 13 vibrators that are placed 8cm from each other. With the belt it is possible to communicate pulses and linear patterns. Model B is explored at the larger parts of the body (arm, chest, back). Figure 8 shows the developed model B.

For both models the MOT-10 is used. The vibrator with a diameter of 10 mm and a height of 3mm is integrated into textile. The weight of the vibrator is 1gram and it works on 3Volt, 70mA. With both models is tested if it is possible to perceive different patterns. Also is explored the experience of the feedback. The use of haptic feedback as interaction medium is a new experience for most users and therefore needs time to learn. The first experiments with haptic feedback indicate that the learning curve increases after short-time practice.

Figure 8. Model B

4.3 Prototyping

Simulating caressing as shown in Figure 9 is the starting point for the development of feedback system for decubitus prevention. There are two types of vibro-feedback, such as impulse and continuous. Continuous feedback appears more common and refers to situations where contact remains over time. Because the feedback is designed as a supporting tool the goal is to design a continuous feedback that is perceived natural an intuitive.

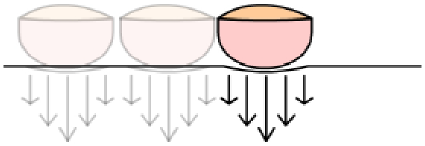

Figure 9. Caress feedback pattern

During the exploration, linear movement is perceived with 13 vibrators. Single pulses that were activated over time and distance communicated different movements. Due to delay and distance between the pulses it was difficult to perceive a connection between to pulses. By decreasing the delay between two pulses or overlapping pulses the relation becomes clearer. The prototype included twelve vibrators that were controlled by a microcontroller.

4.4 Feedback model

For a validation of the tactile feedback a new prototype is developed. The knowledge from smart textiles and the explorations of the model A and B is combined. During the development of the prototype different failures occurred. Noise created by the vibrators affected both the microcontroller as the led-driver. Another problem was the power supply for different components. To stabilize the prototype another led-driver is added and the power supply is divided.

The final prototype that is developed for the validation of the sixteen vibrators. With these vibrators, it is possible to start from eight different points a tactile vibration pattern. The vibrators are controlled with two led-drivers that each control eight vibration motors. Both led-drivers are controlled with a microcontroller that communicates different feedback patterns. The frequency, time, and delay between two pulses can be varied. Figure 10 shows the communication architecture between prototype and microcontroller.

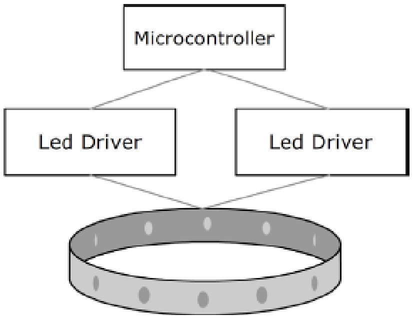

Figure 10. The communication architecture of prototype

4.5 Measurement model

To monitor the interaction between seat and user, pressure sensors are needed. There are a range of pressure measurement systems that are used for different medical applications. FSA seating assessment from Vista Medical Canada is used in this system. The microcontroller A reads the values of the sensors and processes these into matrices that are sending to microcontroller B (Figure 11).

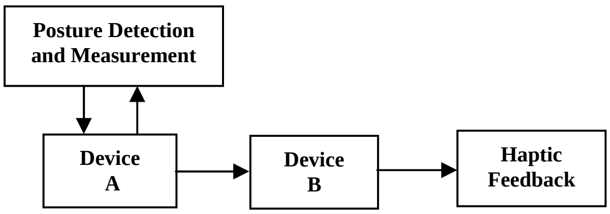

Figure 11. The communication of measurement device

5. Final Design

FSA pressure mat had been selected as the input for the adaptive posture advisory system. The embedded technology into clothing is not selected because there are many limitations that constraints it functionality. Theoretically, the textile with sensors is developed for detecting different physiological elements, but practically it is difficult to embed it into the textile.

Figure 12 shows the system design with pressure measurement method. With the FSA pressure mapping system, an artificial layer is created between the body and the seat. It is measured the pressure between the seat and body. All data from sensors are read and calculated. When the sensor value above its threshold, it will stored in the short memory. The means from the data will store in the long memory. The short memory will count the sensor value. If the sensor value more than 35mmHg for longer than 5 times in a row (1 Hz) or 10 times in 100 measurements, it will send a message to the feedback. For the long memory, it stores the mean value of sensors from nine zones. The results from the calculation will show the risk zones. The mean values also useful as a input to feedback system, where it will guard the user and to warn user to change her/his sitting posture.

6. Conclusion

We have presented the design process as a foundation to develop the posture advisory system for spinal cord injury patient during air travel. The design process of this system is developed using a set of models which enable transformation of information (knowledge and data), i.e. study of spinal cord injury patient and the condition of air travel. The proposed posture advisory system requires expert knowledge because of specific requirements. The conceptual solution is found by variation of known principles. The conceptual design stage is characterized by study on SCI patient and current available technologies that can be used for the development of PAS. With the well-structured conceptual design process in the development of PAS, the solution concepts are reached and fulfill the requirement specification.

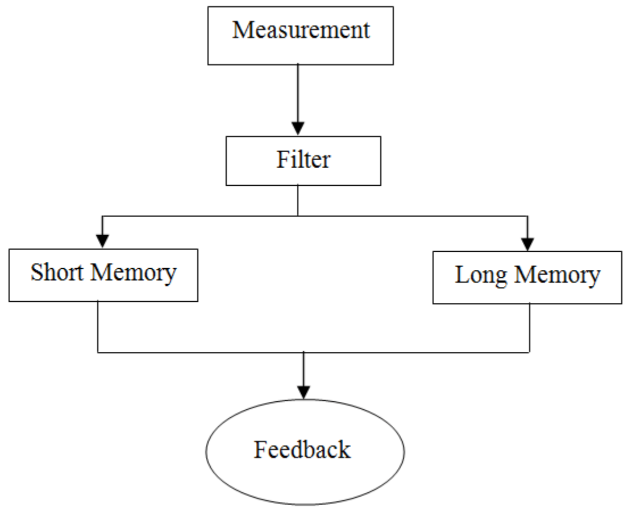

Figure 12. The system design to prevent decubitus

References

[1] Mital, A., Desai, A., Subramanian, A. and Mital, A., *Product development: a structured approach to consumer product development, design, and manufacture*, 2008 (Butterworth-Heinemann, Burlington).

[2] VDI 2221., *Systematic engineering design of technical systems and products*. 1985 (VDI Richlinien, Verein Deutcher Ingenieure).

[3] Black, I., Embodiment Design: Facilitating a Simultaneous Approach to Mechanical CAD. *Computer-Aided Engineering Journal*, 1990, 7(2), 49-53.

[4] Ognjanovic, M. and Obradovic, P., Design process for pressure housing of power systems. *Journal of Engineering Design*, 1998, 9(2), 197-204.

[5] MacLean, K. E., *Application-Centred Haptic Interface Design*, Chapter in Human and Machine Haptics, M. Srinivasan and M. Cutkosky, Eds, 1999 (MIT Press).

[6] Meinander, H. and M. Honkala, Potential Applications of Smart Clothing Solutions in Health Care and Personal Protection, *in Wearable eHealth Systems for Personalise Health Management: State of the Art and Future Challenges*, 2004, 278-285.

[7] Lindeman, R.W., Page, R., Yanagida, Y. and Sibert, J.L., Towards Full-Body Haptic Feedback: The Design and Deployment of a Spatialized Vibrotactile Feedback System, *Proceeding of ACM Virtual Reality Software and Technology*, 2004, 146-149.