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ADAPTIVE POSTURE ADVISORY SYSTEM FOR SPINAL CORD INJURY PATIENT DURING LONG HAUL AIR TRAVEL

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ABSTRACT

Today, air travel is popular as a way of transportation for different purpose such as business and tourism. The numbers of air travel passengers are increasing every year. At the same time the flight distance is increased because of better fuel efficiency and technology advancement of airplanes. Sitting is the most common activity during the flight. The US Department of Health advised the disable people to change their sitting posture frequently to relieve sitting pressures at least every 1 hour, and every 15 minutes for normal people. Decubitus is widely recognized as serious complication for a person with spinal cord injury. Motor paralyses affected a person's ability to respond unconsciously to potential noxious stimuli. 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. The paper describes the development of an adaptive posture advisory system for spinal cord injury passengers. The aim of the system is to reduce the decubitus risk of the spinal cord injury patient during long haul flight.

INTRODUCTION

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. A number of health problems can affect flying passengers. Pressure damage from sitting is one of the common healthcare problems and affects all age groups. People with a spinal cord injury (SCI) are not able to sense the environment in the certain parts of the body due to the nervous system problem and it will increase decubitus risk. SCI patient who spends more than 1 hour in sitting without changing their sitting posture will increases the risks of decubitus ulcer.

In this paper, we present an adaptive posture advisory system (APAS), which is embedded into the aircraft seat. The developed system is to warn the SCI patient and to reduce the risk on decubitus. Different sensors like temperature and pressure are used to provide intuitive feedback to the passenger with SCI. The system measures the interaction between body and the seat. It also provides a feedback to advise passenger to change their sitting posture. A task-based approach defines how the system should adapt in response to events such as failures, changes of context or changes in the requirements.

The aim of the paper is twofold. First, it describes the nature of comfort and discomfort during sitting especially sitting for more than 1 hour. Secondly, it describes an adaptive advisory system that is embedded into the aircraft seat. The proposed system is to reduce the risk on decubitus problem. Different sensors such as humidity sensor, temperature sensor, tilt sensor and pressure sensor are used to provide intuitive feedback to the passenger with SCI. The system measures the interaction of body with the seat and provides feedback to advise passenger to change their sitting posture.

The paper is organized as follows: Section 2 describes the spinal cord injury patient and air travel. Section 3 describes the overview of adaptive posture advisory system. Section 4 describes the concept of APAS. Section 5 describes the multi-sensory model of APAS. Experiment detail with APAS follows in Section 6 and the paper is concluded in Section 7.

SPINAL CORD INJURY PATIENT AND AIR TRAVEL

Air travel is becoming increasingly more accessible to people with the availability of low cost flights and because the airlines are now able to cater for individuals of all ages. Health problems may arise due to anxiety and unfamiliarity

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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. Excessive stress may cause passenger to become aggressive, over-reaction, and even endanger the passenger's health. The stress that occurred can affect the passenger health.

Pressure damage from long hour sitting is one of the common healthcare problems and affects all age groups. For spinal cord injury (SCI) patient who 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 from damage. 85% of the people with SCI experience the damage are directly related to the problem of unable to sense the signals that alert the human body for pain [1]. For SCI patient who lying on the bed, the easiest intervention for reducing pressure is the turning and repositioning of patients at some preset frequency, usually every 2 hours. The goal of turning is to limit the amount of time that tissue is exposed to pressure and limit ischemia. The turning time of every 2 hours appears to be an intuitive intervention with no published data to support this time interval [2].

Pressure sores that can cause the decubitus ulcer during sitting can be relief by training patients to change their sitting posture frequently. Griffith [3] suggested that the pressure under the buttock need to be relied every 30 minutes during sitting, and to lie down for 15 minutes for sitting more than 2 hours. The Agency for Health Care Policy and Research (AHCPR) of the US Department of Health published a clinical guideline to manage pressure ulcer while sitting. The AHCPR recommended body disable individuals should reposition their sitting posture at least every hour to shift the points under pressure. Individuals who are body-able should shift their weight in every 15 minutes [4].

APAS OVERVIEW

Figure 1 shows the architecture of adaptive posture advisory system (APAS) for aircraft seat. The passenger seat is embedded with sensors and actuators. The sensor is designed to detect the SCI passenger's condition such as pressure, movement and posture. The output from sensors will input to central processor and database. The central processor is the core component of the system where it is used to process the input data and send feedback to the actuator. The algorithms for the system is to: (1) advise SCI patient sitting position and support adaptively; (2) provide for better sitting support and propose solution according to SCI patient's personalized sitting preference. 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 the system detects the SCI passenger sitting posture is not changing in long hour, the system will advise the SCI passenger to change the posture; the inference engine will retrieve the preferred seat condition list, adjust the seat softness, select the best seat condition and automatically change the seat condition to reduce the risk on decubitus.

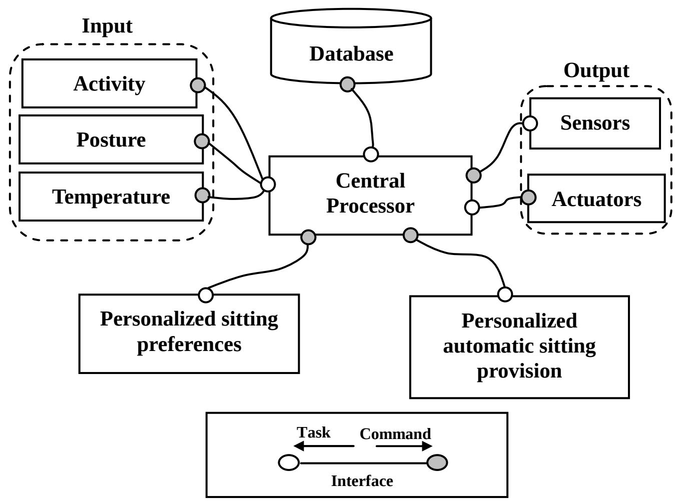

Figure 1. The architecture overview of APAS

THE CONCEPT

The goal of the project is to decrease the ulcers risk while seating. The concept focuses on postural feedback that alerts and advises the user during the peak pressures. During the concept stage, there is a strong focus on privacy, intimacy, and intuition. Two elements were developed during the concept stage. The first element is the input of other element to the output. The input measures different pressure states and the result of the measurement is translated into an output. The output data were sent to multiple actuators.

Tactile feedback is used for human-computer interfaces commonly. It is one of the interaction mediums with specific properties that can provide a natural and private feedback. The artificial touch is not used to integrate in daily life except the vibration of mobile phone. A study about vibrotactile feedback identified two types of vibro-feedback, such as impulse and continuous feedback [5]. Impulse refers to ballistic interaction as knocking. On the other hand, 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 3 shows the comparison of the feedback and information for vibrotactile feedback.

Another challenge is to embed the prevention method into seat or an object that can be attached to the user's clothing. The development of embedded technology already experimented into clothing such as sportswear. For the healthcare area, there is a development of intelligent textiles to monitor patient's condition.

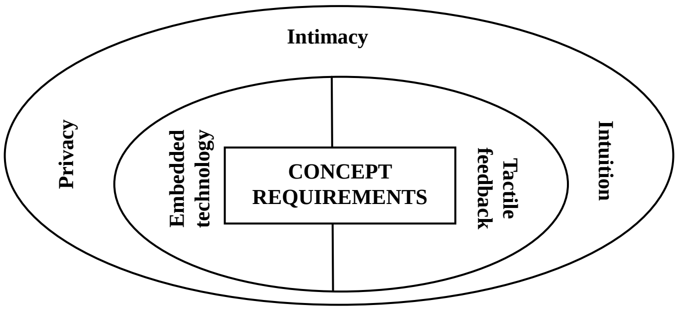

Figure 2. The concept requirements model

	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 3. Feedback and information

MULTI-SENSORY INTERACTION MODEL

User

When designing for people with a spinal cord injury it is necessary to focus on potential and limitations. It is also important to focus on privacy issues because the feedback includes information about the body. Another important aspect is the level of attention. During the concept development, three types of feedback are defined, i.e. support, demand, and play (Figure 4). 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.

Environment

The multi-sensory interaction model is used for virtual environments. The computer-aided design (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 aircraft seat). An interesting factor of this environment is the level of irritation. For this concept, it is important to detect peak pressures.

Figure 4. Conceptual model for feedback

Physical Interface

The physical interface accepts input 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 pressure. When a peak pressure is located, the system translates the pressure into the supporting feedback to guide the user in a position to avoid the peak pressures.

As SCI passenger is unable to sense the body part where the irritation takes place effectively, this information can be translated by using multiple actuators. The actuators as shown in Figure 5 are communicated with different tactile patterns to inform the user about harmful situations. The modality of selection is the multiple vibration units that are used and located on the upper part of the body.

Figure 5. Actuator

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 advise the user to change his posture. As the use of tactile feedback is at its starting phase different experimental models would be developed. Through different experiments, the best method was selected to communicate with the information from the measurement device. Figure 6 shows the multisensory interaction model.

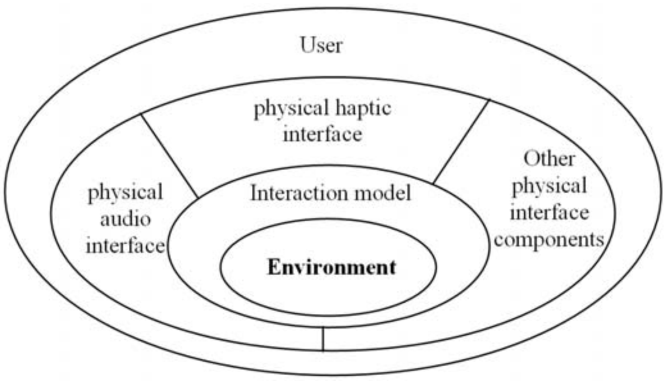

Figure 6. Multi-sensory interaction model (adopted from [6])

Tactile Feedback Experimental Model

The experiment explored how vibration motors can be used to communicate with different types of feedback. 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 100 mm and contains 13 vibration motors. The distance between the vibrators are approximately 2 cm. 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. Two patches are able to communicate 25 messages. Figure 7 shows the design of model A.

Model B is a 1 m belt that is contains with 13 vibrators. With the belt, it is possible for the pulses and linear patterns to communicate. Model B is explored at the larger parts of the body (arm, chest, back). Figure 8 shows the design of model B.

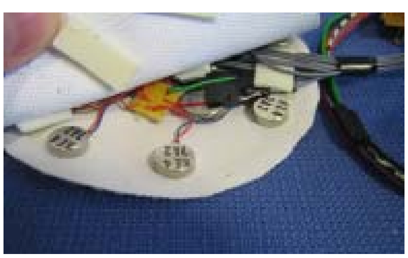

Figure 7. Model A

Figure 8. Model B

For both models the MOT-10 is used. The vibrator with the diameter of 10 mm and height of 3 mm is integrated into the textile. The weight of vibrator is 1 gram and it works on 3 Volt, 70 mA. Both models are tested whether it is possible to perceive different patterns. The use of haptic feedback as the interaction medium is a new experience for most users and therefore it needs some time to learn.

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.

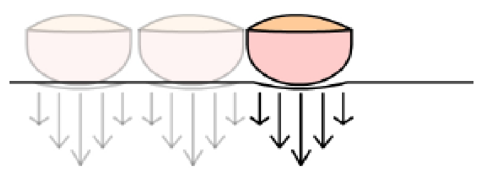

Figure 9. Caress feedback pattern

During the exploration, linear movement is perceived with thirteen vibrators. Single pulses that were activated over time and distance communicated different movements. Because a 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 vibration motors that were controlled with a microcontroller.

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 vibrator affected both the microcontroller and power supply for different components. To stabilize the prototype, another led-driver is added and the power supply is divided equally.

The feedback device is placed around the upper part of the body. With 16 vibrators there are sixteen possible starting points to communicate a direction. For the prevention of decubitus, 8 starting points are interesting for posture feedback. These 8 starting points refer to 8 defined postures. When the user lifts his body, the cushion is able to shape and his body will be relief from pressure concentration. To communicate, a recommendation for a posture change, a vibrator start activating followed by 5 other vibrators at each side. Each vibrator starts with intensity 0 and increases to 16 before it fades out.

The final prototype is developed for the validation of the 16 vibrators. With 16 vibrators, it is possible to start from eight different points a tactile vibration pattern. The 16 vibrators are controlled with two led-drivers that each controls eight vibrators. Both led-drivers are controlled with a microcontroller that communicates with different feedback patterns. The frequency, time, and delay between two pulses can be varied. Figure 10 shows the communication architecture between prototype and microcontroller.

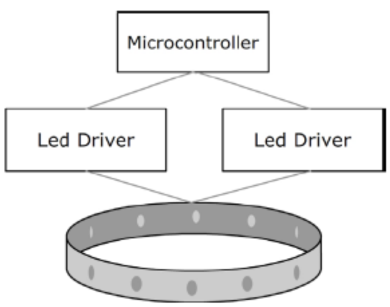

Figure10. The communication architecture of prototype

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 device A reads the values of the sensors and processes these into matrices that are sending to device B (Figure 11).

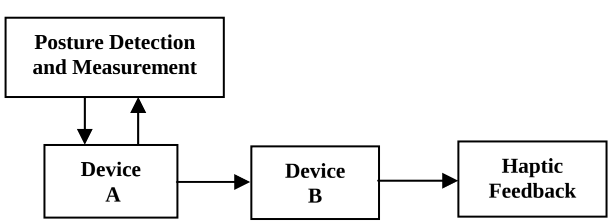

Figure11. The communication of measurement device

The 256 pressure sensors are divided into 9 sections. For each section, the measurement is in certain value crosses the threshold (30 mmHg). With a timer is measured often the threshold is crossed during a set time (20 during 25 seconds with 4 readings a second). When there are 20 readings in 25 seconds that are above 33mmHg, the system will activate a vibration pattern that will guide the user into a new posture. On account of each person has a unique anatomy the segmentation of nine measurement zones needed to be adaptable. The adaptation must ensure that there is a symmetric measurement of the seating surface. Furthermore, the time and threshold needs to be adaptable because the condition of the patient affects the sensitivity of decubitus. Figure 12 shows the schematic of the prototype system.

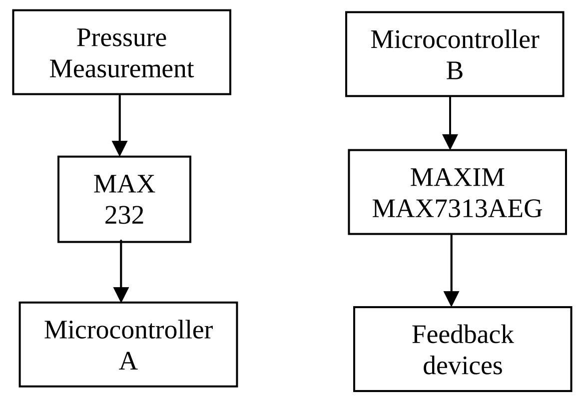

Figure12. The electronic circuit architecture

EXPERIMENT

With the quantitative study, the efficiency of the feedback is evaluated. The result of the test is to support the project with the valuable feedback as well as the issues related to other tactile applications. The goal of the experiment is to test the effectiveness of the tactile feedback and compares with the audio feedback. The test is to compare the spoken audio with (continuous) tactile feedback. The tactile feedback is designed as posture feedback for SCI passengers.

Experiments Administration

26 volunteers (22 males and 4 females) from the Department of Industrial Design were recruited for the experiment. A small range of ages was represented (21 to 27 years old) with the mean of 24 years old. 12 participants were tested with tactile feedback and 14 participants were tested with audio feedback.

The audio feedback consists of four spoken messages (forward, backward, left and right) and communicated to the participants with headphone. The messages are generated by a male computer voice. When the participant receives the audio feedback, he/she has to move the body into the direction according to the instruction.

The tactile feedback group is provided with a belt that contains 16 vibrators. The different patterns are stimulated and guide the participant to change his/her posture within the line of pattern. When the user receives the tactile information, he had to move in line with the direction of the vibration pattern. The belt with tactile feedback is placed around the torso.

In this experiment, the time of reaction was recorded and a questionnaire was used to collect the qualitative data about both feedback mediums.

Measurement System

The experimental seat is equipped with 28 pressure sensors. The seat is used to detect the posture change of the participant. The seat and both feedback system were controlled by the developed software. Figure 13 shows the interface of the measurement system.

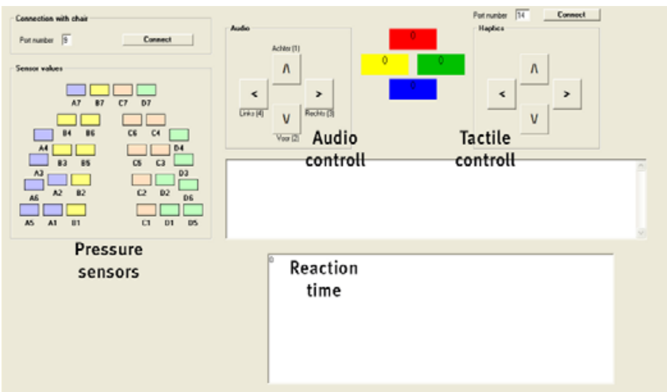

Figure13. The interface of measurement system

Procedure

The participants were briefed with a short introduction about the experiment. All the participants were needed to sign the consent form. Before the start of the experiment, the participants were provided with four feedback examples. Four movements (right, left, front and back) were tested and checked if the system measures the correct changes. After that, the participants were provided with 12 different tactile or audio feedback patterns. During the experiment, the participants watched a soundless cartoon. Figure 14 shows the experimental set up.

After each measurement, the participant is back to the neutral position. Between each feedback, there is a randomized delay between 5 and 20 seconds. After the experiment, the participant filled in the questionnaire and debriefed by the experimenter.

Results

From the experimental results, it can be concluded that there is no significant difference in errors between the understanding of tactile and audio feedback ($F(.59) = 1.944$, $p = .177$). We found that there is a significant difference between tactile and audio feedback for acting time ($F(.86) = 6.964$, $p = .015$). It can be concluded that it take more time to understand or act when received the message in tactile feedback experiment. It is because the tactile command takes more times than the audio command (0.6 seconds). The second reason is the tactile feedback is relatively new to the participants.

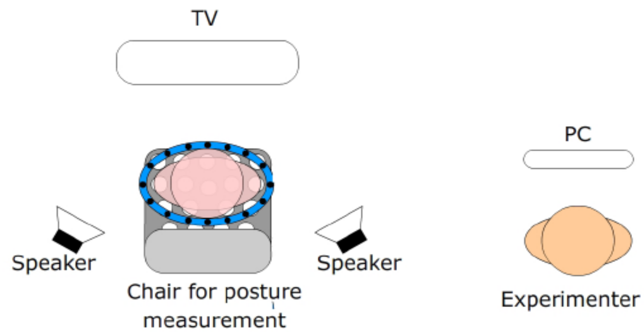

Figure14. The experimental setup

CONCLUSION

We presented the development of a posture advisory system for spinal cord injury patient during air travel. The conceptual design of APAS is developed using a set of models which enable transformation of information (e.g. knowledge and data, the study of spinal cord injury patient and the condition of air travel). The design of the 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 technology that can used for the development of APAS. The future research is to validate the assumption that APAS can really stimulate SCI passengers to change their postures. The further improvement of APAS is in progress.

REFERENCES

[1] Zitdrukverlaging bij mensen met een dwarslaesie, http://www.revalidatiefonds.nl/content/view/ 83/77/, accessed on 2 February 2009.

[2] Jastremski, C., 2002, “Pressure Relief Bedding to Prevent Pressure Ulcer Development in Critical Care,” Journal of Critical Care, 17(2), pp. 122-125.

[3] Griffith, B. H., 1963, “Advances in the Treatment of Decubitus Ulcers,” Surg. Clin. North. Am., Vol. 43, pp. 245-260.

[4] National Information Center on Health Services Research and Health Care Technology (NICHSR) of the Agency for Healthcare Research and Quality (AHRQ), Managing Tissue Loads, http://www.ncbi.nlm.nih.gov/books/bv.fcgi?rid=hstat2.section.9144, Accessed on 20 April 2009 .

[5] Lindeman, R.W., Page, R., Yanagida, Y. and Sibert, J.L., 2004, “Towards Full-Body Haptic Feedback: The

Design and Deployment of a Spatialized Vibrotactile Feedback System," Proceeding of ACM Virtual Reality Software and Technology, pp. 146-149.
[6] MacLean, K. E., 1999, "Application-Centred Haptic Interface Design, Chapter in Human and Machine Haptics," M. Srinivasan and M. Cutkosky, Eds, MIT Press.

