Smart Rehabilitation Garment for Posture Monitoring

Q. Wang, W. Chen, *Senior Member IEEE,* A.A.A. Timmermans, C. Karachristos, J.B. Martens, P. Markopoulos

***Abstract*—Posture monitoring and correction technologies can support prevention and treatment of spinal pain or can help detect and avoid compensatory movements during the neurological rehabilitation of upper extremities, which can be very important to ensure their effectiveness. We describe the design and development of Smart Rehabilitation Garment (SRG) a wearable system designed to support posture correction. The SRG combines a number of inertial measurement units (IMUs), controlled by an Arduino processor. It provides feedback with vibration on the garment, audible alarm signals and visual instruction through a Bluetooth connected smartphone. We discuss the placement of sensing modules, the garment design, the feedback design and the integration of smart textiles and wearable electronics which aimed at achieving wearability and ease of use. We report on the system's accuracy as compared to optical tracker method.**

I. INTRODUCTION

Accurate posture monitoring can be helpful in several different areas of rehabilitation. For example, exercising posture control can improve patients' ability to maintain an upright position of the spine, which can be beneficial in avoiding musculoskeletal pain [1][2]. Sensing technology can help patients acquire awareness of their posture and correct it when necessary. Similarly, during neurological rehabilitation of upper extremities, e.g., for victims of stroke, spinal cord injury, and multiple sclerosis, patients tend often to develop compensatory strategies using alternative movements and muscle groups to compensate for the diminished capability of their arm(s) [3][4]. For these patients, sensing technology can potentially help self-monitor and correct their posture when they move outside a pre-specified range, in a way analogous to how therapists monitor and correct posture of patients during traditional physical therapy training sessions. Monitoring posture through technical means opens up the possibility of independent training, (without continuous therapist supervision), providing feedback to end-user as active monitoring system, which can allow a therapist to train several patients at once, or even to enable tele-rehabilitation scenarios. In this paper we discuss the development of Smart Rehabilitation Garment (SRG) with wearable sensing technology (see Fig. 1) to address both the above scenarios: sustaining an upright position for avoiding spinal pain as well as notifying patients of compensatory trunk movements during arm-hand training.

Figure 1. Smart Garment Design

II. RELATED WORK

Wearable sensing technology for posture monitoring and correction has been attracting increasing attention. Researchers working on such technologies have attempted to integrate miniaturized computing devices and sensors into textile fabrics for rehabilitation interventions. For example, Bleser et al [5] proposed a home-based exercise trainer system based on a sensing jacket for capturing user's motion. Vigour [6] exemplifies how stretch sensors can help monitor upper body movements, though the emphasis of this research is on the aesthetic integration of posture feedback to the garment rather than on reliable measurement.

Nevertheless, obtaining reliable measures is key to the effective use of posture monitoring for rehabilitation. To ensure correct execution of arm-hand training exercises, the thoracic angle to the vertical plane needs to be monitored. Earlier studies [7], have identified the appropriate placement of sensors for measuring the thoracic angle. Timmermans et al used sensors on the arm and torso of stroke patients during training with the Philips stroke exerciser [8], in order to ensure the correct execution of exercise. Beursgens et al, developed a vest for monitoring the patient's posture while playing a serious game intended to support arm-hand rehabilitation [9][10]. However, these garments are very loose and the sensor placement is only approximate.

An recent extensive survey indicated that wearable rehabilitation technology has great 'promise and provides many technical benefits' [11], but aspects like wearability, comfort and aesthetics are often neglected. A potential explanation for this state of the art could lie in the novelty of this technological field, where most effort is still directed towards the development of sensors and establishing their measuring accuracy rather than in their integration into

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Q. Wang, W. Chen, J.B. Martens, P. Markopoulos are with the Department of Industrial Design, Eindhoven University of Technology, 5612 AZ, Eindhoven, The Netherlands (e-mails: q.wang@tue.nl, w.chen@tue.nl, j.b.o.s.martens@tue.nl, p.markopoulos@tue.nl).

A. Timmermans is with the BIOMED- REVAL Research Institute, Faculty of Medicine and Life Sciences, Hasselt University, Belgium (e-mail: annick.timmermans@uhasselt.be).

C. Karachristos was with the Department of Industrial Design, Eindhoven University of Technology, 5612 AZ, Eindhoven, The Netherlands, (e-mail: karachristos.x@gmail.com).

complete systems. For example, a recent literature survey [12] of wearable sensor system to support upper extremity rehabilitation, could only find 19 articles reporting the development of systems beyond the proof of concept, only 4 of which were integrated into a complete exercise system that could support training and another 5 in gaming applications. We note however that particularly for supporting rehabilitation, next to the accuracy it is important to consider practical and even mundane aspects of garment design that influence directly the wearer's experience, e.g., material texture, tightness of fit, ease of putting on and taking off, as well as aesthetic aspects of clothing, etc.

Below, we describe the design and implementation of SRG and an evaluation of the reliability of the measurements obtained.

III. SRG System Concept

A. System Overview

The Smart Rehabilitation Garment (SRG) consists of a garment with integrated smart textiles and wearable electronics and an application runs on android-based hardware. We discuss how it can support the two application scenarios: monitoring correct neck posture and providing feedback regarding the thoracic angle during arm-hand training.

- **Detecting thoracic posture.** A therapist asks the patient to sit up straight and then to adjust to a more slouched position, and then marks a personalized range of postures which will be considered acceptable. Subsequently the patient can get on with exercises or daily tasks, (e.g. studying), while the system notifies them when they slouch outside the designated range.

- **Detecting compensatory movements**. Before starting the execution of the exercises, patients should set the target value range with the help of therapists and depending on how much the disease has affected them. After completing this step the patient can proceed with the execution of the exercises comprising the rehabilitation program. When the detected compensation movement (Fig.2.a) exceeds the set range, the user will receive feedback from a vibration motor attached to the corresponding point on the patient's garment and smartphone's visual and audio feedback. The main idea of the system is to enable patients to gradually adjust their posture until maintaining the right position becomes an automatic process.

B. Angle Calculations

The two scenarios above can be supported by tracking two points on the spine:

- For the thoracic posture the difference in the slope between vertebrae T1 and T5 provides a measurement of the slouching.

- For detecting compensatory movements, the average of the angle of the sensor with respect to the vertical plane, provides an indication of the thoracic angle (see Fig. 2).

The positioning of the garment should be done properly so that the sensors can be placed in the correct positions in the shoulder and the torso of the patient. This is a prerequisite for our system as the sensors are calibrated to work properly in

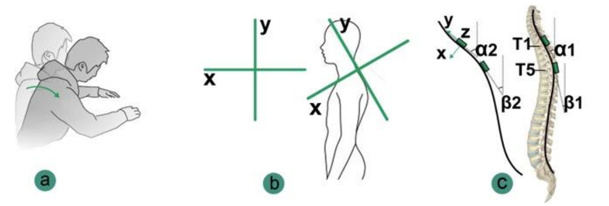

Figure 2. Angle Calculations. (a) Compensation Movement. (b) Zero Degree Calibration. (c) Calibration Model

specific spots on the body of the patient. As shown in Fig. 2.b, torso sensor is calibrated to its zero position as the human skeleton is not completely straight.

As discussed above, in order to monitor accurate trunk compensation, we take T1 and T5 to define thoracic angle corresponds to the flexion and extension movements of the upper trunk. In this way, assume the readings obtained by the two IMUs are α and β (see Fig. 2.c), then the thoracic static angle γ can be defined estimated as the average of α and β, and the thoracic bending angel Δ is estimated by the average difference of α and β.

IV. Prototype and Architecture

A. Design Process

The SRG we proposed is a result of iterative design process, where different components were integrated in different versions of the garment, and evaluated with informal user tests.

The first iteration (Fig. 3.a) provided a proof of concept. Using two accelerometers attached to a normal long-sleeve t-shirt, we develop algorithms based on the filtered raw data, and succeeded to provide a good indication of trunk flexion and extension. We placed one accelerometer on the chest and another one at the acromial base, monitoring trunk and shoulder movement. However, the accelerometer data did not provide an accurate enough measure, and the intuitive placement of the sensors was not suitable for reliably measuring the thoracic posture[13] [14].

In the second iteration we conducted explorations from 5 aspects: a) In order to provide accurate sensing and to use the same sensors for the application scenarios (thoracic angle) we placed the sensors on vertebrae T1 and T5 of spine. b) Wearable pattern, for integrating wearable electronics into soft fabric, shown as Fig. 3.b; c) Garment design, improving the wearability; d) Mobile application development.

Finally, after the third iteration we propose a modular design consisting of multiple sets of garments and one set of wearable sensors. An inertial measurement unit (IMU)

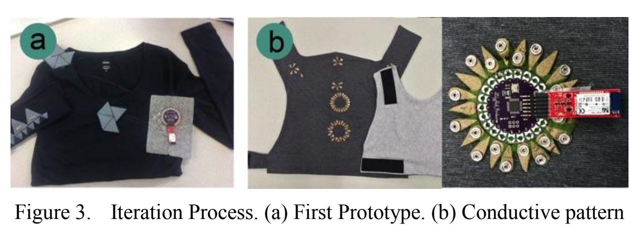

Figure 3. Iteration Process. (a) First Prototype. (b) Conductive pattern on second prototype.

replaced the accelerometer for more precise measurements. Based on the removable design of the wearable electronics, users can have not only one choice during their rehabilitation exercise at home. The sensing garment should look friendly and familiar and offer better engagement.

B. Hardware Architecture

The SRG system consists of the following components: a) Two Adafruit 9-Dof IMU Breakouts; b) One LilyPad Arduino 328 Main Board as the central node reading sensor data from the 2 IMUs; c) A Bluetooth Mate Silver module for wireless communication between the garment and smartphone; d) A LilyPad Vibe Board embedded close to the sensor providing vibration feedback.

The connections between the various components of the system as described below in the relevant section was performed with silk conductive threads and not with jumper wires, in accordance with the main design goal that the garment should be applied to the body as much as naturally as possible. As for the communication between the system and the smart device, a Bluetooth protocol was selected.

C. Application Interface

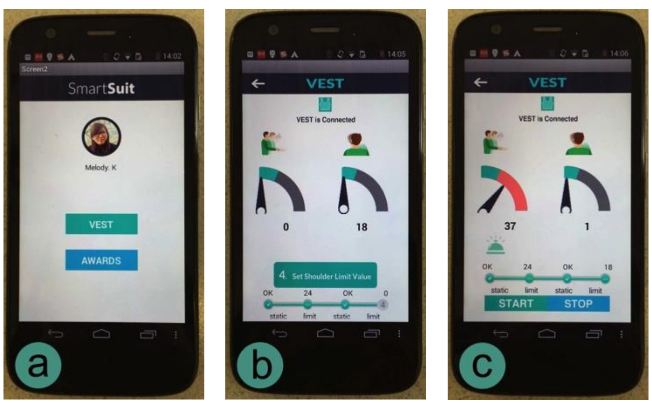

Figure 5. Interface design. (a) Login. (b) Set personalized start position and target value range. (c) Visual feedback when motion is over range.

A mobile Android application was designed aiming for a very simple and usable interface. Fig. 4 illustrates the interface design at different stages of interacting with the system. When the patient is out of range value other than the vibration feedback that he feels from the corresponding sensor(s) he can also hear an alarm signal from his/her smartphone device.

D. Garment Design

The garment is a separable and adjustable design and separate in front and back parts, for ensuring the accurate sensor position and measurement. The process of putting it on is shown in Fig. 5: (1) prepare the two pieces of garment in flat and vertical; (2) adjust the Velcro to guarantee that the

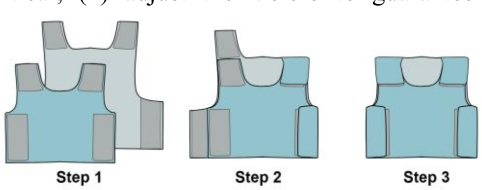

Figure 6. Modular Design

shoulder sensor is located at the angulus acromial from the spinal scapulae; (3) finally attach the wrist belt and ensure the sensors are located at C7-T1, T4-T5. Combined with the elastic fabric, this concept provides a solution for fitting people of different sizes, without influencing the comfort by tightness; this is a key factor for correct position of the sensors during spinal movements and may also be very important for supporting long term use.

E. Conductive textiles integration

We set out to design the conductive network for the connection between wearable sensors. Both the front and back parts are designed in two layers, while the wearable electronic connections are sewn with Shieldex® silver coated nylon yarn and conductive fabric on the inner side of the back part. The resistance of the conductive garment was calculated based on the sample of the conductive threads, the conductive yarn used in the garment with a resistivity under 100 Ω/m, and by adjusting the conductive paths to balance between the aesthetics pattern on garment and the resulting resistance value. Modular design is another feature, various sets of garments for different training scenarios and one set of wearable electronic modules. Every garment is equipped with conductive connections and the modules can connect to the garment by conductive fabric pattern.

V. Evaluation

A pilot study was set up and administered in order to evaluate the performance of the garment for measuring the thoracic angle. Compared to a commercial optical tracker (*PST-55/110 series*) that uses infrared lighting to detect optical markers from *ps-tech* (see www.ps-tech.com). Experiment data are presented by the mean value, standard deviation, and root mean squared errors (RMSE). Written consent was acquired from each participant prior to the experimental sessions. This was a non-clinical study without any harming procedure and all data were collected anonymously. Only healthy participants were involved to register simple motions in a non-invasive way, and without collecting any personal data on the participants. Therefore, according to the Netherlands Code of Conduct for Scientific Practice, ethical approval was not sought for the execution of this study.

A. Experiment setup

Figure 4. Experiement Setting

By using the 3D motion capture system one L shaped hard piece with two optical markers was attached to each sensor. The raw data provided by the system are the space coordinates and we calculate the angles between two space vectors by applying the calculation model. Seven subjects without any related pathology (4 female and 3 male) participated in this experiment. After putting on the garment they were introduced to how to interact with the application to control proposed system. Then participants were asked to stand in a marked position in front of the optical tracker. Fig. 6 shows the experiment setup. The experiment procedure is as follows: 1) stand straight with feet flat on floor, keep still (last for approximately 2 seconds to implement the calibration process) then click button on smartphone to set personalized "0" as the starting position; 2) bend forward until the App displays 15° and keep still; 3) bend forward further to 30°, 45°, 60° and 75° separately. 4) The subjects repeated the exercise series three times, for every target angle randomly. While the participants stood still, the observer recorded the data with the optical tracker.

B. Results

TABLE I. EVALUATION RESULTS

Angles	15	30	45	60	75
MEAN	17.45	33.39	48.27	63.47	79.08
RMSE	2.61	3.66	3.71	3.79	4.56
SD	1.14	1.29	1.97	1.62	1.93

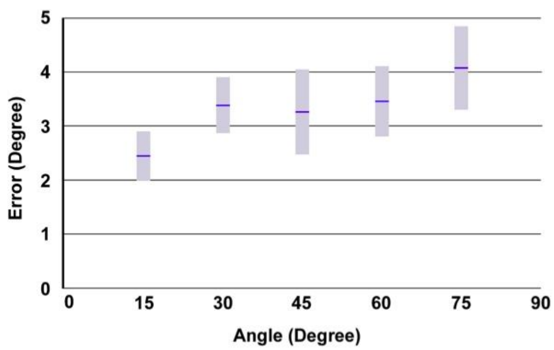

Figure 7. Mean Value and Standard Deviation

Table 1. presents the average RMSE (root mean squared error) and standard deviation results. The RMSE increases with the flexion angle. The reason may be that the sensor is placed in loose contact with the skin when the angle increases. The RMSE presents the average deviation extent, and the global RMSE value is 3.57. The accuracy achieved is comparable to the state of the art in wearable technologies as shown in a recent survey [12] while arguably improving on aesthetics and wearability substantially. The average value of the three times measurements from 7 subjects are illustrated in Fig. 7.

VI. FUTURE WORK

In the future we will develop the system in following steps: (a) Carrying out clinical tests of the garment for the two applications scenario shown and both standing posture and seated posture. First, an evaluation of the usability/user friendliness, and of the credibility for the support of therapy, and of motivational aspects of feedback via the SRG during rehabilitation will be performed. Subsequently, we shall examine whether using the vest to support regular treatment can improve training outcomes. (b) From a technical perspective the smartphone interface will be extended to provide historical data and remote monitoring scenario.

VII. CONCLUSION

We set out to design a garment to support posture monitoring to support two scenarios: prevention of spinal pain and avoiding compensatory movements during arm-hand training. We have proposed a design of the smart rehabilitation garment, providing posture feedback directly on the jacket using vibration motors and graphically on a connected Android smart phone. The integration of smart textiles design to wearable projects contributes to the implementation of the reliable and comfortable monitoring system. The system can be used in different context and training approaches and the adjustable design ensures the sensors can stay in the correct position during training. Future steps aims to improve and extend the capabilities of the smart rehabilitation garment, but also to establish its usefulness in a clinical context.

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