Wearable Posture Monitoring System with Biofeedback via Smartphone

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***Abstract*— In this paper a novel portable posture monitoring and feedback system is proposed. System is designed to be unobtrusively used during daily activities and provide alternative solution to traditional bracing used in treatment of scoliosis. System consists of wearable sensor network for posture data acquisition, wireless data transmission and conventional smartphone for data processing, visualization and vibrating feedback generation. Special data acquisition board is designed for data sampling from sensor network and wireless transmission to smartphone. A custom made Android application is used for real time data processing, current posture model visualization, data logging and instantaneous feedback. System was tested for posture monitoring and feedback generation on multiple test subjects. Tests demonstrated systems effectiveness on improving posture related behavior and ability to help subject to hold specific reference posture performing similar task as traditional bracing.**

***Index Terms*— biofeedback, portable computing, posture monitoring, wearable technology.**

I. Introduction

Posture monitoring could have beneficial effect in treating spine related diseases such as scoliosis. Scoliosis is a three dimensional deformation of spine. The most common characteristics are bending of backbone in coronal plane and rotation of vertebrae, which result in various deformations of human posture. The development of the disease usually takes place during growth period, so in the risk group are children aged from approximately ten years and up to maturity. Around 2 to 3 percent of all adolescents are diagnosed with this condition and if it is not moderated in time the most severe cases can lead to serious health problems [1], [2].

The most popular treatment method for scoliosis is a hard material brace. This brace mechanically forces patient to hold specific therapist assigned corrective posture which prohibits development of further deformations (Fig. 1.). For this treatment to be effective, the brace must be custom made for each specific patient according to type and rate of deformations [3]. In addition, bracing must be used up to 23 hours a day which is both physically and psychologically challenging for a teenager to perform.

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Figure 1. Traditional brace for treatment of scoliosis.

To overcome these drawbacks alternative treatment methods such as biofeedback have been studied. Biofeedback can improve self awareness in natural environment and several studies confirm that it can be valuable method for treating scoliosis [1], [2], [4]. Instead of applying mechanical force, patient could be warned to perform corrective posture himself whenever unwanted position is detected. Elimination of hard braces could significantly improve the quality of life during treatment as well as the effectiveness, as the patient must actively perform corrective posture himself. In order to provide such a feedback, posture must be monitored in real time with reasonable resolution to detect various human back deformities associated with scoliosis. This rises several challenges like developing convenient wearable sensor system for detailed posture monitoring and portable data processing.

In [5] several attempts to measure human posture have been summarized. The most promising solutions make use of 3D inclination measurements from accelerometers, as this approach provides small, low-power sensors which can potentially be integrated in garment almost invisibly. As most of the methods use relatively small amount of sensors [6], [7], [8], they fail to provide detailed information of human posture and various possible deformities.

In recent years there has been a rapid advancement of cellular devices. A significant number of people carry smartphone during almost every daily activity, which makes it an ubiquitous computing device. Modern smartphones have impressive computing power, comparable to desktop computers just a few years ago. This computing power, together with wireless and

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networking capabilities make them an attractive portable data processing platform for mobile sensor systems. In addition, integrated sensors and actuators can help to obtain some additional context information or provide interactive data feedback and visualization.

There are number of studies that prove feasibility of smartphone use as data transfer and/or processing unit. In [9] several smartphone operating systems have been compared for use in system which combines external sensor communication, data processing and visualization for medical purposes. Remote monitoring systems where smartphone or PDA is used as a central controlling unit are described in [10], [11], [12]. A foot pressure analyzing system consisting of custom made sensors, Bluetooth data transfer to smartphone and custom made Android application is described in [13]. In [14] a custom made Android application obtains data from body mounted sensors, to provide feedback of received sun radiation amount. These studies justify that smartphones can be used as generic devices for data acquisition and processing in a number of fields especially wearable technologies, medical telemonitoring, etc.

In this paper a complete system, that can be used during daily activities for posture monitoring and biofeedback generation is proposed. System consists of body mounted sensor network and portable data processing on Android smartphone.

Paper is structured in five sections. In section II our proposed method is described. Section III includes four subsections witch are dedicated to description of our experimental setup. Testing and results are showed in section IV, and section V serves as conclusion stating out limitations and future work.

II. Proposed Method

Our proposed solution consists of two parts. First, is wearable sensor system for data acquisition and transfer, which includes body mounted sensor network, microcontroller and Bluetooth module to provide wireless data transfer. Second part is conventional smartphone with custom made application for sensor data processing, visualization and feedback generation. Structure of proposed posture monitoring and feedback system is visible in Fig. 2.

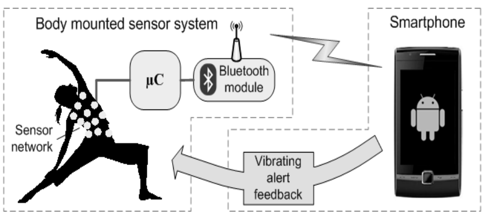

Figure 2. Structure of posture monitoring and feedback system.

- In wearable sensor system part a sensor network attached to human back is used for posture data acquisition. Sensors are evenly spread around back surface providing detailed information about posture deformities. Microcontroller is used to sample data from sensors and send them to Bluetooth module for wireless data transmission. Bluetooth transmission is chosen to provide convenient data transfer to smartphone application as most of available smartphones have integrated Bluetooth transceivers.
- Sensor data processing is implemented in Smartphone application to provide system portability and reduce development complexity and cost. Smartphone application receives data from sensor network via Bluetooth. Processing is done to reconstruct geometric model of sensor network alignment thus obtaining data about posture. By comparing this model to previously stored reference decision is made whether alerting feedback must be generated. Feedback is provided using speaker or vibrating motor integrated in smartphone.

III. Experimental Setup

A. Posture monitoring

For posture measurement, previously proposed method for 3D surface shape recognition is used [5]. In this method data from tri-axial accelerometer network is used to approximate geometric shape of surface. If this sensor network is mounted on human back, it can provide detailed information about human posture.

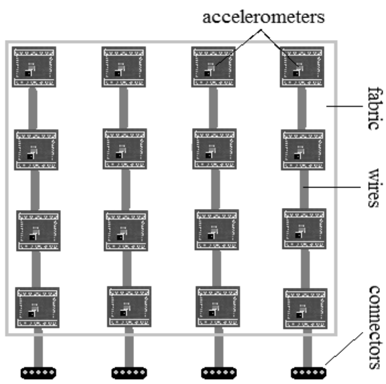

Figure 3. Structure of accelerometer network.

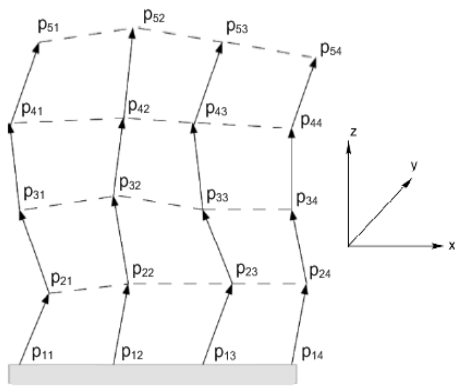

Figure 4. Construction of approximated 3D shape [3].

Network of 16 interconnected sensors arranged in 4 by 4 grid is used (Fig. 3.). Each sensor is mounted on human back and corresponds to a particular segment. Model of human back that corresponds to the actual posture is constructed by a set of mutually connected fixed length vectors, where each of them corresponds to particular sensor (Fig. 4). In static conditions accelerometer readings contain acceleration only due to gravity. Using this phenomena it is possible to obtain inclination angle of each sensor thus obtaining its corresponding vector inclination angle [5]. Approximated model is defined by a set of points p_{ik} (i – row, k – column) in 3D space which describe vector end points. Each p_{ik} consists of x, y and z coordinate.

B. Data acquisition

For data acquisition and wireless transmission specially designed circuit board is used. Body mounted sensor network is wired to this board. MSP430 series microcontroller is used to sample data form sensors with sampling rate of 50 Hz. Then simple averaging of 5 samples is done to smooth vibrations in signal and reduce amount of data to be transferred wirelessly. Averaged data are sent to BTM-112 Bluetooth module which uses SPP (Serial Port Profile) for wireless transmission to smartphone. System is powered with three 3 AAA rechargeable batteries and voltage regulator is used to provide required supply voltage.

C. Feedback

Algorithm that compares current state with previously stored data of corrective posture is used for calculation whether to provide vibrating feedback. As stated in subchapter III A, human back model is defined by set of points in 3D space. At the beginning of use, initial calibration is required to acquire data about reference model of desired posture. Similar to current state model this reference is defined by a set of 3D points ref_{ik}. This data is used to find parameter Δp which describes difference between current state and reference model. Δp is calculated as average distance in 3D space from each point in current data set to corresponding point in reference data set. If total number of sensor rows are defined with r and columns with c, then this average distance can be found:

$$\Delta p = \frac{\sum_{i=1}^{r}\sum_{k=1}^{c} \| p_{ik} - ref_{ik} \|}{rc}. \quad (1)$$

If Δp is grater than some experimentally determined threshold value $\Delta thresh$, then feedback is generated to warn about poor posture. At first vibrating motor is turned on for one second to warn about deviation from reference posture. If value of Δp does not drop below value of $\Delta thresh$ during next five seconds, vibrating motor is turned on until this condition is true.

D. Smartphone application

There are wide availability of different mobile devices running Android operating system. Android open source approach makes application development fast and relatively easy as many examples and tools are widely available [15]. Because of these advantages we chose Android platform as data processing unit in our system.

A custom Android application was developed for sensor data reception, processing, logging, approximated posture visualization and feedback generation. Basic flow chart of application operation is visible in Fig. 5.

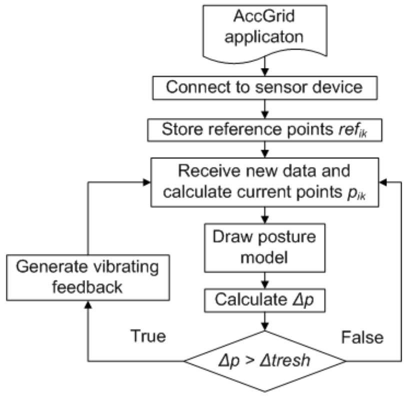

Figure 5. Android application feedback control flowchart.

In initial step application establishes Bluetooth connection with wearable sensor device. After smartphone and sensor device have been paired, initial calibration is required to obtain reference model of correct posture. With sensors mounted on body, subject must perform desired posture and store corresponding data ref_{ik} in smartphone memory by pressing "Save state" button in the application. Also approximate height of subject, and threshold value $\Delta thresh$ must be set. Height of subject is used to estimate length of the vectors, from which approximated posture model is constructed. $\Delta thresh$ define allowed rate of difference between current posture model and reference. Higher $\Delta thresh$ means that subject can move more freely away from reference posture before feedback is generated.

After initialization, current posture monitoring can be performed. This is done in cyclic manner, where in each cycle a set of sensor data is received and processed in real time (faster than arrival of the next data set). First, calculation of posture model defining points p_{ik} and construction of graphical posture model is done using method described in section III b. Graphical model provide visual reference of current posture that is monitored by system. Then the parameter Δp is calculated using (1). If Δp is greater than $\Delta thresh$, feedback is generated.

Additionally, application can log all posture data on memory card for later analysis. Also in a given time period application can register amount of time when bad posture ($\Delta p > \Delta thresh$) was detected. This is provided as ratio in percent relative to a full time period of system. Both of these functions can be used for statistics and validation of feedback effectiveness.

IV. Testing and Results

As a result we built experimental device for posture data acquisition and developed custom Android application for data processing and feedback generation. The user interface of application is visible in (a), (b), and (c). In (a) interface screen of Bluetooth connection establishment is visible. (b) shows the processing screen where user can save reference state, run the real-time processing and change parameters such as feedback threshold value, height, etc. (c) contains screen where approximated posture model visualization is constructed. The constructed model corresponds to current posture visible in (d), whereas the small lines indicate the shape of previously stored reference posture.

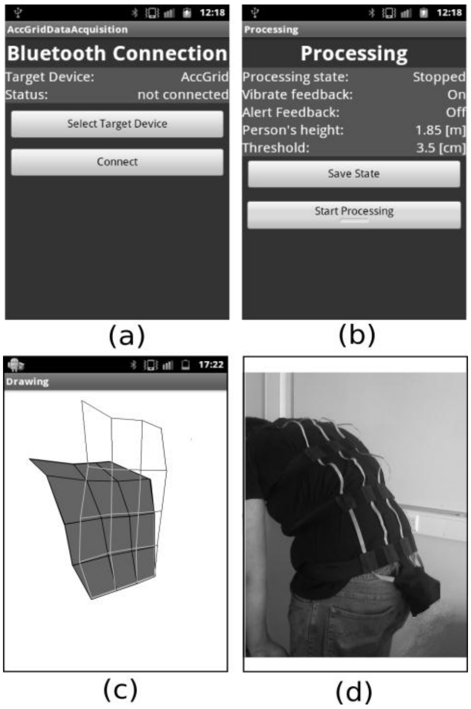

Figure 6. Android application screens and sensor device

To evaluate proposed systems influence on users posture, a test study was done. Experimental device was tested on four healthy subjects. Sensors were mounted on subject back with elastic bands as visible in (d). Data were logged while subjects were working at desk in sitting position (not leaning against chair). Position when sitting with straight back without slouching or bending sideways was used as reference. Each subject logged their posture data with two different feedback threshold values – $\Delta thresh$ = 3 cm and $\Delta thresh$ = 5 cm. Each threshold value was used for approximately half an hour. Obtained data from all subjects are summarized in Fig. 7 Histogram illustrates distribution of logged Δp values, which determines the offset from reference posture. Each set of bars corresponds to 0.5 cm wide interval, and show relative amount of time in % when posture with Δp in this interval was detected. The discontinued lines indicate boundaries where in each threshold case feedback alert was switched on. Impact of feedback is clearly visible, as in both cases noticeably decreases the relative time spent in postures with Δp exceeding the threshold value. With feedback threshold values $\Delta thresh$=3 cm and $\Delta thresh$=5 cm, the time spent in "correct" posture ($\Delta p<\Delta thresh$), was respectively 89% and 90%. However, with threshold $\Delta thresh$ = 5 cm, only 49% of the time was spent with $\Delta p<3$ *cm*, which shows feedback threshold value influence on subjects behavior.

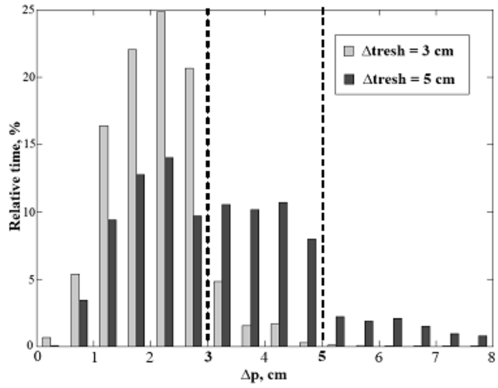

Figure 7. Four subject average posture statistics with different feedback threshold values.

V. Conclusions

Test results of the experimental setup proved systems potential in recognizing different posture deformations and producing feedback if undesired posture is detected. Testing showed that around 90% of time subjects spent with posture similar to the reference within the threshold interval. There is noticeable reduction in distribution of Δp after threshold values, which indicate the presence of feedback alert. This proves that biofeedback is efficient way to control users posture.

As the sensor network is able to provide detailed data about different deformities, it is reasonable that system could detect scoliotic curves and provide feedback for patients who are diagnosed with scoliosis. This kind of system can help user to obtain specific required posture, thus it could serve as alternative to traditional hard material braces and help to reduce development of scoliosis.

Sensors used in this method are small and lightweight which potentially allow them to be integrated into garment almost invisibly. Also wires could be integrated into clothing which allow unobtrusive use of the system during daily activities. This can provide more convenient and visually appealing treatment method for scoliosis, which both are essential aspects for patients diagnosed with this condition.

This study confirms that modern conventional smartphones provide excellent portable platform for sensor data processing which can make system highly portable and convenient for daily use. This approach also considerably reduces system development complexity and cost, as part of the hardware that is necessary for systems functionality is already provided. Our custom made application was tested on multiple Android smartphones. Most tested units can be classified as middle class devices with processor clock frequencies starting form 600 MHz. However, this computing power proved to be enough to implement real-time algorithms for multi sensor data processing and construction of graphical model. This proves that modern high-end smartphones equipped with multi core processors and running clock frequencies well over 1 GHz are suitable for complicated processing of large data sets.

One drawback of smartphone inclusion in system architecture is the necessity of Bluetooth data transfer, as it is the most convenient way to send data to smartphone. This solution has relatively high energy consumption (around 90% of total in our sensor system part), and it limits the battery life of both sensor system and smartphone. Despite this, our wearable sensor system powered with 3 AAA batteries provides more than 20 hours of operation which is reasonable for our purpose.

Within the scope of this paper, Android applications functionality is sufficient to demonstrate portable data processing and feedback generation capability. However, beneficial for the system would be improvement of application. For example, application could be implemented as a background process in Android operation system, to allow full phone functionality during posture monitoring process.

Additionally future work includes increasing number of sensors for better resolution, developing more sophisticated data processing algorithm for improved feedback control and improving acceleration data filtering to enhance system performance in dynamic conditions. Also system must be evaluated during longer periods of time including tests with real patients diagnosed with scoliosis.

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REFERENCES

[1] B. Dworkin, N. Miller, S. Dworkin, N. Birbaumer, M. Mrines, and S. Jonas, *et al*., "Behavioral method for the treatment of idiopathic scoliosis," in *Proc. National Academy of Sciences of USA*, April, 1985, pp. 2493-2497.

[2] M. S. Wong, A. F. T. Mak, K. D. K. Luk, J. H. Evans, and B. Brown, "Effectiveness of audio-biofeedback in postural training for adolescent idiopathic scoliosis patients," *Prosthetics and Orthotics International*, 2001, pp. 60-70.

[3] M. D. Rigo, M. Villagrasa, and D. Gallo, "A specific scoliosis classification correlating with brace treatment: Description and reliability", *Scoliosis*, 2010, 5:1.

[4] W. Y. Wong, "Development of a posture monitoring system," PhD thesis, The Hong Kong Polytechnic University, 2009.

[5] A. Hermanis and K. Nesenbergs, "Grid shaped accelerometer network for surface shape recognition," in *Proc. 13th Biennial Baltic Electronics Conference*, Tallinn, Estonia, October 3-5, IEEE 2012, pp. 203-206.

[6] H. J. Luinge and P. H. Veltink, "Inclination measurement of human movement using a 3-D Accelerometer with autocalibration", *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* March 2004, vol. 12, pp. 112-121.

[7] C. Goodvin, E. J. Park, K. Huang, and K. Sakaki, "Development of a real-time three-dimensional spinal motion measurement system for clinical practice", *Med Bio Eng Comput*, vol. 44, no. 12, pp. 1061–1075, Dec 2006.

[8] W. Y. Wong and M. S. Wong, "Measurement of Postural Change in Trunk Movements Using Three Sensor Modules", *IEEE Transactions on Instrumentation and Measurement,* August 2009, vol. 58, pp. 2737-2742.

[9] J. Woodbridge, A. Nahapetian, H. Noshadi, M. Sarrafzadeh, and W. Kaiser, "Wireless Health and the Smart Phone Conundrum," *Sigbed Review*, 2009, vol. 6, no. 2, pp.11.

[10] M. J. Morón, A. Gómez-Jaime, J. R. Luque, E. Casilari, and J.A. Gázquez, "Analysis of a telemonitoring system based on a bluetooth body area network using smartphones," in *Proc. 2nd International Conference on Applied Informatics and Computing Theory*, Stevens Point, Wisconsin, USA, 2011, pp. 17-22.

[11] E. Seto, E. Martin, A. Yang, P. Yan, R. Gravina, and I. Lin, et al., "Opportunistic strategies for lightweight signal processing for body sensor networks," in *Proc. Petera Conf.*, Greece, June 23-25 2010.

[12] J. M. Cano-García, E. González-Parada, V. Alarcón-Collantes and E. Casilari-Pérez, "A PDA-based portable wireless ECG monitor for medical personal area networks," *IEEE Melecon*, Benalmádena, Spain, May 16-19 2006, pp. 713-716.

[13] S. Pfaffen, P. Sommer, C. Stocker, R. Wattenhofer, and S. Welten, "Planipes: Mobile foot pressure analysis," in *Proc. mHealthSys '11*, Nov 1, Seattle, Washington, USA, 2011.

[14] T. Fahrni, M. Kuhn, P. Sommer, R. Wattenhofer, and S. Welten, "Sundroid: Solar radiation awareness with smartphones," in *Proc. UbiComp'11*, Beijing, China, September 17–21, 2011.

[15] Android Development Tools. (Nov 1 2012). [Online]. Available: http://developer.android.com/tools/index.html

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