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A Novel Technique for Analysis of Postural Information with Wearable Devices*

Vala Jeyhani[1], Shadi Mahdiani[2], Jari Viik[1], Niku Oksala[3], and Antti Vehkaoja[1]

***Abstract*— These days, as many jobs involve sitting behind desks and working with computers for extended periods, more and more people are suffering from back problems. Maintenance of an appropriate posture may prevent future back problems. There are various medical methods for studying postures abnormalities of the back but most of these methods are limited to be utilized in diagnostics and follow-up of treatment and not used in a continuous or in a preventive manner. Therefore, designing and developing methods for measuring, analyzing and reporting of posture information, aimed for prevention of future back problems is of fundamental interest. In this work, a proof-of-concept system, including five accelerometer sensor units is presented. Additionally, an index, which we call spine inclination index (SII), is introduced and used for converting the raw data to meaningful presentable information. Initial evaluation includes measurements with six subjects. Subjects were asked to mimic accentuated kyphotic, straight and accentuated lordotic postures while sitting. Our results show that the designed device and SII index are able to distinguish between different postures very well. In addition, since this device measures the inclination angle of different spinal postures, its output can be directly compared with other widely used methods.**

I. INTRODUCTION

IN today's modern life, where human's life style is largely affected by the increasing use of information technology, awareness of possible health risks is an important task. The increase of time spent sitting behind desks and working with computers causes work related musculoskeletal disorders (WRMSDs) of the upper extremities [1] and has a huge influence on the body posture. This problem appears in other jobs in different fields too. For instance, nurses [2] and dentists [3] are reported to be in a high risk of back problems. Additionally, it is reported that the prevalence of low back problems is even higher in non-working population comparing to working population, for both men and women [4].

Low back pain is reported non-specific, i.e. without a specific underlying cause, in up to 90% of cases [5]. The lifetime prevalence of non-specific low-back pain is reported as 60 – 70% in industrialized countries (one-year prevalence 15 – 45%, adult incidence 5% per year) [6]. The prevalence rate during school age is approximately similar to what is seen in adults [7], [8]. These statistics show the importance of considering the back pain for all the ages and all the sectors of society.

There are various methods for diagnosis of postural abnormalities. Standing radiograph is the gold standard method for this purpose [9]. The alternative methods include the DeBrunner kyphometer [10], the biophotogrammetry (using e.g. markers) [11], flexible ruler [12], [13], and inclinometer [14], [15]. These methods are not suitable for on-line or continuous measurement and they are used only when a subject becomes symptomatic and seeks medical attention. Therefore, these methods cannot be utilized in preventive manner and they require a professional to perform the measurement. Thus, there is a huge need for a device capable of continuous measurements without professional help, utilized in a preventive manner. This kind of devices would be capable of providing continuous feedback on the subject and thus aiding in the correction of abnormalities and prevention of manifestation of irreversible problems. Therefore, having a wearable device which is capable of continuously measuring the posture information, analyze them in a well representative way and report them to the person and (if needed) physicians can prevent serious problems which might happen with aging.

Recently, there has been an increase in using inertial sensors in measurements of human posture. The reliability of these devices has been assessed in different studies. Wong et al. [16] showed that by using three tilt sensing modules, reliable postural and motional information could be achieved. Grid shaped networks of sensors for treatment of scoliosis have been presented and their application has been extended to wearable devices [17] . Washizawa et al. [18] have proposed an algorithm for removing the effect of motion components in these devices. Also, some other methods such as using inductive sensors sewn on fabric [19] have been proposed for posture estimation in wearable devices. Some research has been conducted on improving the accuracy of posture measurements [20]. Additionally, inertial sensors have also been used in similar applications like analysis of movement dysfunctions [21]. This interest and the growing desire in embedding the health care methods in wearable medical devices require automated, well representative and accurate posture data analysis methods.

In this work, a measurement system including five accelerometer sensors is developed and a novel signal analysis approach for representation and assessing the spinal posture

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[1]Vala Jeyhani, Jari Viik and Antti Vehkaoja are with BioMediTech Institute and Faculty of Biomedical Sciences and Engineering, Tampere University of Technology, Tampere, Finland vala.jeyhani@tut.fi jari.viik@tut.fi antti.vehkaoja@tut.fi

[2]Shadi Mahdiani is with VTT Technical Research Centre of Finland Ltd shadi.mahdiani@vtt.fi

[3]Niku Oksala is with Tampere University Hospital and Faculty of Medicine and Life Sciences, University of Tampere, Finland niku.oksala@uta.fi

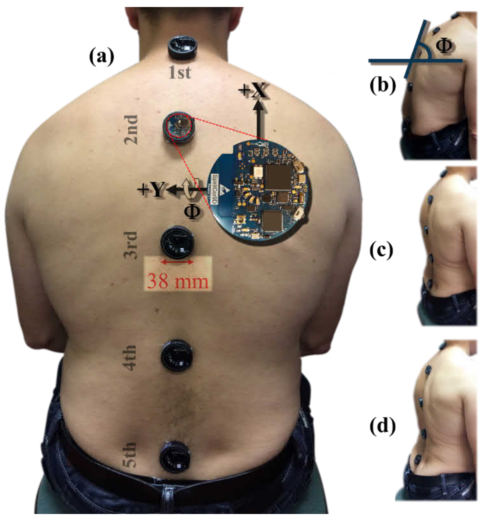

Fig. 1. The placement of the sensors and the axes of acceleration sensitivity (a). Kyphotic (b), straight (c) and lordotic (d) postures emulated by subject number 3. The angle of interest is indicated by ϕ (b).

is proposed. The performance of the device and the method was evaluated with six subjects.

II. METHODS

A. Measurement System

A measurement system consisting of five measurement units was developed for this work. In each measurement unit, 3-axis acceleration signals are sensed, processed and digitized by a MPU9250 multi-chip module and transferred to a local microcontroller. The devices are battery operated and capable of wireless communication for sending the measurement data[1].

The measurement resolution is 16 bits with a full-scale range of $\pm 2\,\mathrm{g}$. For the posture measurements, the data rate was set to 10 samples per second and the bandwidth of the signals was limited to $5\,\mathrm{Hz}$.

The measured samples are packed into a 2-byte packet and are sent via Bluetooth Low Energy (BLE) to a *central* device. In this system, the BLE constructs a one (central) to five (*peripherals*) multi-connection network. UART service of BLE is used in the communication. The Central device used is a BLE dongle from Nordic Semiconductor that can be connected to a computer. The received data from the measurement devices are gathered by the dongle and then sent to the computer to be stored. A graphical user interface (GUI) was designed in LabVIEW to ease the measurement process. The final analysis of the stored signals was done in MATLAB.

B. Measurements

Before performing the measurements for each subject, the devices were put on a stable table and one recording was performed. This recording, which acted as the sensor calibration, was then used in the final analysis process to compensate for possible misalignment caused by soldering or the enclosure of the devices.

Six subjects (one female and five males), with the age of 32 $\pm$ 3.69 years, ranging from 29 to 38 years, and the BMI of 24.8 $\pm$ 2.9 kg/m^2, ranging from 22.3 to 30.0 kg/m^2. participated to the study. All the subjects were reported as healthy and had no history of structural back problems or surgery. The subjects were informed about the test procedure before and they signed the consent form. The subjects were asked to emulate three sitting postures: straight, slouched (accentuated kyphosis) and extended (accentuated lumbar lordosis). All the phases of the measurement were kept the same for the all the subjects. The test was repeated three times for each subject.

Fig. 1a shows the placement of the sensors and information about the axes of acceleration sensitivity. According to the orientation of the devices, y-axis is not sensitive to the postural changes among the considered postures and is removed from the calculations. An example of the considered postures is also illustrated in Fig. 1b, 1c and 1d. Angle ϕ in 1b shows the angle of interest.

Five sensor devices were used for the measurements. The first and last devices were placed on the seventh cervical vertebra (C7) and fourth lumbar vertebra (L4), respectively. The rest of the peripheral devices were placed between these two devices with equal distances. The C7 vertebra was found by running the hand inferiorly to locate the most prominent bump. Then, the iliac crests were located and the vertebra at the same level as them was considered L4.

Three seconds of measurement (thirty samples) were recorded from each subject while they were asked to stay still in each posture. The amount of fluctuations in the signals were then examined in MATLAB and results showed that they were smaller than $10\,\mathrm{mg}$.

C. Data Analysis

The recorded data, which were in units of g (acceleration of gravity), were first averaged and then converted to angle (in degrees). Then, the calibration values were subtracted from all the angles. Finally, the deviation of the angle of the fourth sensor from $90°$ was subtracted from all the angles to compensate possible upper body tilt. The conversion to inclination angle is done using the following formula.

$$\phi = atan2(A_X, A_Z) \times 180/\pi, \qquad (1)$$

where A_X and A_Z show the acceleration of gravity of x and z axes in g, respectively (see Fig. 1).

1) Spine Inclination Index (SII): To facilitate the presentation of postural information and classification of the data into different postural abnormalities, an index is introduced for converting all the inclination angles measured from the sensors to a single numbers. SII is calculated by first uniformly distributing the measured angles in polar coordinates and then extracting two areas formed by the polygon below and above the x-axis. More specifically, the polygon is constructed by first dividing the whole 2π radians into N (number of sensors, in our case $N = 5$) parts and

[1]A demonstration of the device can be found at www.spiritcor9d.xyz

then locating the measured inclination angles from sensors on the lines with the radius of $\frac{2\pi}{N}$. The following formulas may be used to convert the measured angles to coordinates on a polar plane.

$$\psi_{i,x} = \phi_n \cos(\alpha_i) \tag{2}$$

and

$$\psi_{i,y} = \phi_n \sin(\alpha_i) \tag{3}$$

where ϕ_n shows the n-th measured inclination angle and α_i is considered as

$$\alpha_i = \frac{2i\pi}{5}, \quad 0 \leq i \leq 4. \tag{4}$$

The area of the polygon above the x-axis constructs the first part of the index. The second part uses the area below the x-axis, excluding the area between the first and the last device. The top panel in Fig. 3 shows these areas for the straight posture. Finally, the upper part area is subtracted from the lower part area.

Since SII index distributes the postural information in positive and negative sides of the x-axis, the effect of height of the subjects on postural analysis is automatically compensated.

2) Individual calibration: Because the inclination angles of the sensors and thus the values of SII indices in specific posture vary slightly between people, a calibration is performed for each individual subject. A calibration coefficient α is defined for each subject in "straight" posture as the proportion of the average area of the pentagon above the x-axis divided by the average area below the x-axis. Alpha is then used to scale the area below the x-axis in each individual measurement before subtracting the areas in SII calculation.

III. RESULTS

A. Inclination Angle

Fig. 2 shows the inclination angles measured from all the subjects, in different postures and in the three measurements. In this figure, the middle point in each bar represents the mean value of that group of values and the bars extend to the standard deviation of that group of measurements. The angles are represented with respect to horizontal direction extending to ventral side of the body. It can be seen that the measurements from each sensor overlap in different postures and extracting the amount of abnormality is not straightforward. However, the mean values follow a representative trend for different postures (solid lines).

Fig. 3 shows the final postural presentations for two of the subjects. In these diagrams, each dashed line can be considered as one axis on which the information from one device is located. Since the goal here is to illustrate the changes in posture, the scale of the axis is not shown. However, the scale is the same in all the figures. The origin indicates 0° and the vertices of outer pentagon show 140° tilt of each measurement device. Only one of the measurements of each subject is illustrated. The difference between different postures can be clearly seen in the plots.

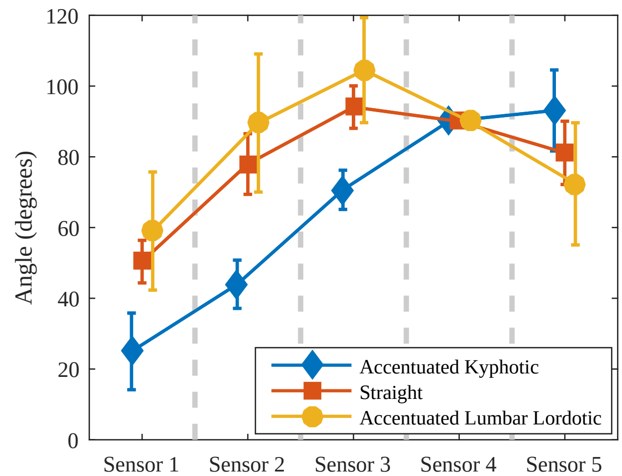

Fig. 2. Inclination angles calculated from all the subjects, in three measurements and in three different postures: accentuated kyphotic, straight and accentuated lumbar lordotic are shown. The circle, square and diamond markers represent the mean values between all the measurements for each device. The bars extend to standard deviation of each group of measurement for each device. The small difference between the horizontal positions of the data points in one group is to improve the clarity.

In all the subjects, the diagram, which shows the normal posture, has the most symmetric shape with respect to the x-axis. On the other hand, when the subject imitates the kyphotic and lordotic postures, the diagram becomes asymmetric. For all of the subjects, the diagrams representing kyphotic postures are pulled to down and left while the upper area is diminished and the ones related to lumbar lordotic are pulled to top and right. The inter subject variability might be due to differences in the natural straight posture, in emulating the postures, and in sensor location.

B. SII Analysis

Fig. 4 shows the SII analysis for the measured inclination angles from all the subjects in all three tests. The middle points indicate the average value and the whiskers extend to standard deviation of that group of measurements. The SII index increases when changing the posture from straight to lordosis and diminishes when moving towards kyphosis. This single value not only discriminates normal and abnormal postures, but may also be utilized as a trigger to notify the user of poor postures.

IV. DISCUSSION AND CONCLUSIONS

In this work a wearable device, including five accelerometer sensors was presented. Six subjects participated in this test. The signals from three axes of accelerometers were recorded and analyzed. Additionally, an index, which we call spinal inclination index (SII), was introduced for converting the postural information to a single meaningful number.

Our results show that different postures can be differentiated by using the developed method. Additionally, it is worth mentioning that since this device measures the inclination angles, its output can be directly compared to other methods.

The developed device and the new posture analysis approach have a strong potential in bad postural habitual

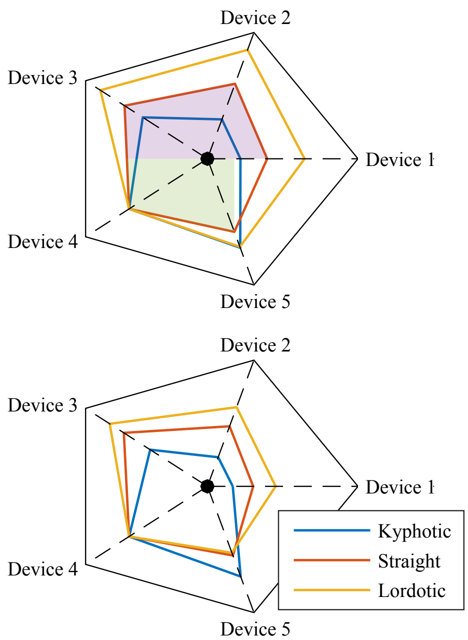

Fig. 3. Inclination angles for two of the subjects. There are five data points on each curve that represent the inclination angles measured from each device. Each curve represents one of the examined postures.

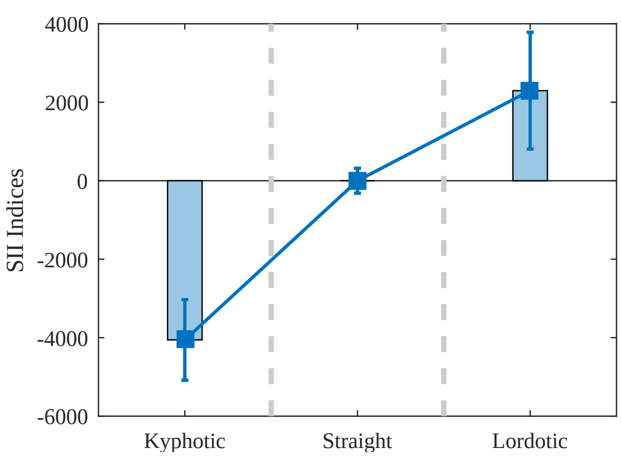

Fig. 4. SII analysis for inclination angles measured from all the subjects in all three tests. The boxes show the mean of the values while the bars on each box are extended to the standard deviation of that measurement values.

prevention. The availability of electronics can add many valuable features to this device, which are not feasible in other posture analysis tools. For instance, saving the postural information continuously while doing daily work, easy transmission of the information and automatic alarming or tactile feedback can be added to this device.

In the future work, more subjects will be considered and all the tests will be performed with supervision of physicians. The comparison of the results and SII to a reference measurement and their direct relation to kyphosis and lordosis angles will also be considered.

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