A Novel Mobile Wireless Sensing System for Real-time Monitoring of Posture and Spine Stress

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Abstract— **Poor posture or extra stress on the spine has been shown to lead to a variety of spinal disorders including chronic back pain, and to incur numerous health costs to society. For this reason, workplace ergonomics is rapidly becoming indispensable in all major corporations. Making the individual continuously aware of poor posture may reduce out-of-posture tendencies and encourage healthy spinal habits. We have developed a novel wireless mobile sensing system which monitors spine stress in real-time by detecting poor back posture and strain on the back due to prolonged sitting or standing. The system provides a new method of measuring spine stress at both the back and the feet by integrating posture sensors with strain sensors. Posture and strain data is collected by means of a posture sensor at the neck and weight sensors at the feet. Data is transmitted wirelessly to a central processing station and real-time feedback is provided to the user's mobile device when sustained bad posture is detected. Moreover, the position of the patient (sitting, standing, or walking) can be determined by analysis of the weight sensor data and is visualized in real-time, along with back posture, at the central station by means of a graphical animation. Finally, data from all sensors is stored in a database to enable post processing and data analysis, and a summary report of daily posture and physical activity is sent to the user's email. The use of centralized processing allows for high performance data analysis and storage at the central station which enables tracking of the individual's progress. We demonstrate effectiveness of our system in simultaneously monitoring posture and position by testing in numerous situations.**

Keywords- Spine health, real-time monitoring, inclinometer, load cell, wireless, mobile

I. INTRODUCTION

Spine stress caused by poor back posture or extensive standing or sitting in fixed positions can result in pain and discomfort, and may lead to unpleasant changes to soft tissue and bone, resulting in bone spurs and intervertebral disc damage, and other spinal musculoskeletal disorders [1]. The resulting back pain can eventually become chronic. These spinal problems are a burden to society because of the high costs of health care incurred as well as the negative repercussions as to employee disablement, absence from work, and the individual's overall life quality. Poor posture is common among adolescents as well as employees who work for prolonged hours. It is estimated that about 80% of adults will experience back pain at some point in life, and roughly 10% of those will suffer a relapse [2]. Moreover, spinal injuries are second only to the common cold as a cause of absence from work, with many of these problems emerging from poor posture habits. Since more spinal problems will inevitably lead to higher health costs and lower productivity, helping people maintain healthy spinal habits and reduce spine stress during daily activity is of considerable benefit. In particular, we found that making the user continuously aware of poor posture will reduce out-of-posture tendencies and encourage healthy spinal habits [3]. Increasing patient awareness of poor posture means that the patient can use her own back muscles to correct the spinal curvature, instead of using external support devices which could cause physical and psychological discomfort [3].

In this work, we investigate the use of mobile sensing technology to monitor spine stress in real-time during daily activity. The system monitors both back posture and patient position (sitting, standing, and walking). For poor posture, the system provides feedback to the patient when the time spent out-of-posture exceeds a threshold that can be specified by the doctor. For patient position, the system monitors increased pressure on the back due to undesirable positions such as standing or sitting in a fixed position for a long period of time. These situations are unhealthy not only from a spinal perspective but also from the more general perspective of a reduction in physical activity. The system will measure the weight at the user's feet and detect whether he or she is standing, sitting, or walking at any given time. Furthermore, a daily summary report is automatically generated and it provides an account of the amount of time during the day that the patient is standing, sitting, or walking, to enable her to track her progress. The report also provides daily information related to posture angle and severity of poor posture. We use an inclinometer, positioned at the neck, to measure posture angle and load cells, positioned at the soles of the feet, to measure weight. Data from the sensors is acquired and transmitted to the central processing station using a wireless data acquisition module.

The concept of mobile sensing systems for other types of activity recognition has been investigated in [4], which describes a 'Mobile Sensing Platform', a small wearable device that uses multimodal sensors to monitor physical activity to encourage physical exercise and healthy habits. There have also been studies to monitor the posture habits of patients and provide corresponding feedback, as in [3, 5, and 6]. The system we propose is a novel scheme in that both a person's posture and weight are simultaneously measured, with real-time feedback in the form of an SMS provided in case incorrect posture is detected. Central rather than local processing is used to enable more complex data analysis and to reduce power consumption on the mobile system, and allows storage of data for tracking of the patient's progress. We use a novel algorithm to predict the distant patient's position at any moment of time based on data acquired from the weight sensors, and a graphical animation of the patient that mirrors his or her posture and position is displayed in real-time on the central processing station. Finally, all sensor data is stored in a database that can be used for post-processing analysis to track the patient's spine stress progression over time.

The rest of this paper is organized as follows: Section 2 presents the existing techniques which measure posture in real time. Section 3 discusses our approach and device design, in addition to the algorithms we implemented. Section 4 analyzes the results obtained and the effectiveness of the system. Finally, Section 5 concludes with a summary of our findings and future work

II. Related Work

The use of sensor technology for dynamic monitoring of spine health has generally been limited. Some of the existing systems for monitoring spine health typically include x-rays and photogrammetric systems. However, these systems cannot monitor spine during daily activity and thus cannot provide the awareness that comes with monitoring and user feedback. Some systems that can be used for dynamic monitoring of spine health include electromagnetic tracking systems and potentiometric goniometers, and are discussed in [5] along with their limitations. Another system, designed specifically for posture monitoring, was proposed in [3]. The system uses accelerometers and gyroscopes. It is a smart garment that monitors poor posture of the spine during daily activities and provides corresponding feedback signals to the user through a buzzer. Three sensors were placed at the upper trunk, middle trunk, and pelvis, and the corresponding posture angles were calculated as the difference between the measurements from adjacent sensors. The system was able to prove the effectiveness of user feedback in correcting posture. Data processing was local using microcontrollers. Other related work for dynamic activity monitoring, but unrelated to spine health, includes 'The Mobile Sensing Platform' [4], discussed above.

III. Methodology and Device Design

A. Wearable Device Components

We used an inclinometer (Digi-key; part# 551-1017-ND) (1), a device which measures the positive and negative angles in a given plane, to measure the forward bending angle of a person's back. As for the weight, we used load cells fixed inside one's shoes (2). The load cells (measurement specialities; part# MSP6954-ND), measure the strain placed by each foot. As for the wireless link between the sensors and the base station, we used a Wi-Fi data acquisition device (National Instruments; NI-WLS 9215) (3) which wirelessly transmits the sensor data it receives to the base station. (4) is the battery used to power the sensors and DAQ module. The components are shown in Figure 1. The system when worn by the patient, with a comfortable attach and pocket for inclinometer, is shown in Figure 2.

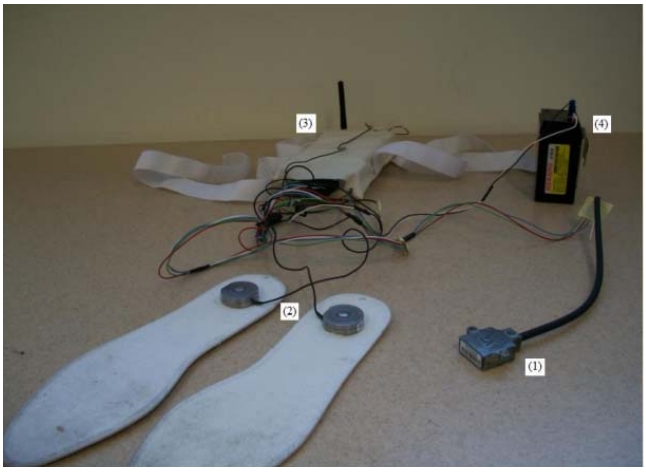

Figure 1. Wearable components of spine stress monitoring system: Inclinometer(1), Load cells(2), Wireless DAQ (3), and battery (4)

Figure 2. Spine stress monitoring system worn by patient

B. Measuring Inclination

In order to measure the forward bending angle of a person's upper back, and thus determine to what extent a person is bending down, we fixed the inclinometer at the neck, at the intersection of the shoulders and the spinal cord. We experimented with placing it at different positions and found that the posture dynamics were most accurately captured when the inclinometer was placed as indicated.

The requirement of the inclination algorithm is to detect when the angle made by a person's back exceeds the angle threshold for a sustained period of time. The two parameters of the algorithm are the angle threshold T_p and the time threshold T_t, which can both be specified by the doctor or user. The algorithm starts by reading streaming posture angles continuously. To perform the analysis, it averages the values coming in every stream and continuously compares each average to the angle threshold. If the stream average exceeds the angle threshold, a timer starts. If the user adjusts his or her posture within the time, then no warning message is sent and the algorithm restarts. If the user does not correct his posture within the time threshold T_t, a message is automatically sent to the user's mobile device (e.g cell phone) warning him/her to correct his/her posture. Every time the average of a stream is calculated, the angle and the corresponding timestamp are saved. The timestamp corresponds to the time at which the last value in the stream was sampled. A pseudocode of this algorithm can be found in Figure 3.

```
Ak: an input stream array of posture angles of size k, from DAQ analog
output
Tt: threshold for time, user-defined
Tp: threshold for posture angle, user-defined

while(system is running) do begin:

      boolean bad_posture = true;

      read values in Ak
      find average_angles = average of the values in Ak;
      find timestamp = time of recording of last value in Ak;

      writeToCSVFile(average_angles, timestamp);

      if (average_angles > Tp) do:
            start timer;

            while (timer < Tt) do begin:
                  Ak = next array of angles of size k;
                  average_angles = average of the values in Ak;

                  if (average_angles < Tp) do:
                        break;
                        bad_posture = false;
                  end
            end //end while, time up

            if (bad_posture = true) do
                  sendSMS(user);
            end
      end
end
```

Figure 3. Inclination algorithm

The reason that average values of a certain number of the inclination angles are considered rather than individual values is to render the algorithm more robust to temporary variations. In this way, if a person bends down for an insignificant period of time, the timer is not triggered. Similarly, if a person only temporarily straightens his or her back and then returns to an incorrect position, the timer is not reset and the user will be judged to have remained the whole period of time in an incorrect posture situation.

C. Measuring Strain and Position

Load cells placed in the user's shoes are used to measure the stress exerted on the spine during the day. This allows the patient to determine how much strain was placed on the spine over the course of a day due to prolonged standing or sitting in fixed positions. Such analysis can be useful not only for spine health but also for improving the user's fitness if it is found that the user does not engage in sufficient physical activity. Different activities and positions may be preferable for different users, depending on that person's age and health condition. Note that the use of strain data is not limited to monitoring patient position, which we have demonstrated as an example application, but it can also be used to monitor increased pressure on the back due to continuous lifting of heavy items, or to detect imbalance in walking resulting from structural spinal conditions such as adolescent idiopathic scoliosis. The requirement of the strain detection algorithm is to determine the position of the user at every sampled period of time. Position takes on categorical values: 'walk', 'sit' or 'stand'. Then analysis can be performed to determine for how long the user was standing, sitting, or walking. As before, we based our analysis on the averages of streams of data rather than on individual values. For every stream, the output of the algorithm is 'sit', 'stand', or 'walk'. The data of both load cells, one in the left foot and one in the right, is collected and analyzed as follows:

1. If the difference between the weight values of the two load cells in each foot is "large", then the person is walking at that particular instant of time
2. If the difference is "small", then the person is either standing or sitting.
3. If the difference is "small" and the average of the actual values are "small" then the person is sitting; otherwise, the person is standing.

The definitions of "large" and "small" are also parameters that are user-defined and that are usually dependent on the weight and build of the person. For example, less heavy people will need a lower threshold to be judged as standing. As before the output for every stream is saved and the values and corresponding timestamps are then stored in the database.

D. User Interface

The user interface allows the user or doctor to specify the preferences for a number of parameters and thresholds. Moreover, it allows real-time monitoring of both numerical and graphical data related to the user's activity. The doctor can use the graphical display to monitor the distant patient using Wi-Fi to visually and easily track the patient's status. The graphical display is in the form of an animation figure that mirrors the posture and position of the user in real time (shown in Figure 4). This display serves not only for monitoring but also as a test for accuracy by comparing the display with the user's actual position. The graphical display indicates whether the user is sitting, standing or walking. In case the user is sitting, the graphical display changes according to his or her back posture.

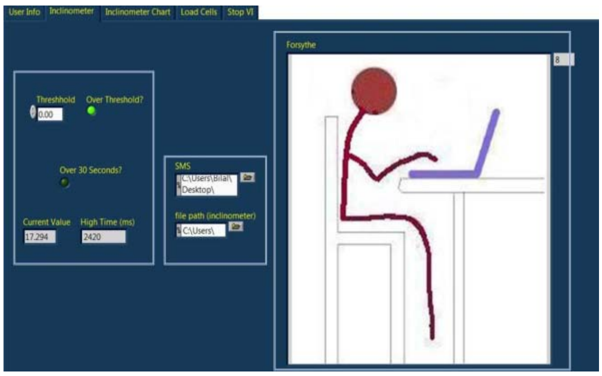

Figure 4. User Interface

E. User Feedback

User feedback is implemented in two forms: a real-time SMS when sustained bad posture is detected, and a summary report of the day's activities that is sent by email to the user at the end of the session. The SMS message is received by the user when incorrect posture is detected. The summary report, which is sent by email, is generated at the end of the day from the database where the data is stored. The report contains information such as the average posture angle per day, the number of SMS notifications sent per day, the percentage of time during the day spent sitting, standing or walking, and other relevant information. This summary feature was enabled by having a central processing station and a database.

IV. EXPERIMENTS AND RESULTS

A. Inclination

We tested the inclinometer in a variety of scenarios. Figure 6 shows one of the tests, where the user was first in a correct posture position, then bent over, then briefly straightened up before going through a period of fluctuation. We verified that after the user bent down below the threshold, the timer started. If the user spends the specified amount of time in an incorrect position, a message is sent to her cell phone in real-time with minimal delay. And as the user bent down, the animation figure in the interface mimicked the user's actions, and bent down its back in proportion to the user's bending.

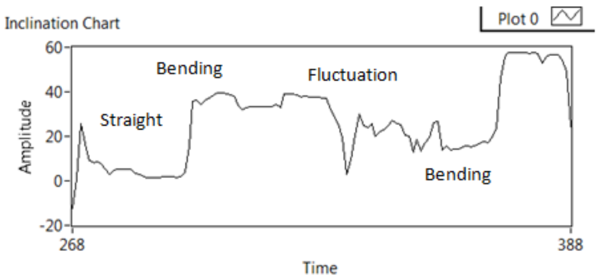

Figure 6. Inclination Chart

B. Weight

Similarly, we tested the load cells in several different scenarios comprising walking, sitting, and standing. Figure 7 shows the results of one such test case. . As can be seen from the figure, when the user was sitting, the mean of load cells was low and the mean of difference was low. When she was standing, the mean of load cells was high and the mean of difference was low. When she was walking, both were high. Furthermore, the animation figure in the graphical display was able to successfully mimic the user in real-time; he stood when the user stood, walked when she walked, and sat down when the user sat down.

V. CONCLUSIONS AND FUTURE WORK

We have developed a wireless mobile sensing system which can achieve real-time monitoring of both poor back posture and stress on the spine deduced through measurements at the feet. The system ensures patient awareness of poor posture in real-time through user feedback by SMS, encouraging the persistence of healthy spinal habits and reducing poor posture tendencies. The use of central processing enabled complex data analysis and storage of patient data for additional post-processing analysis and tracking of patient progression. A friendly animation figure at the central station correctly mirrors the distant user in real time, and a summary report email is sent to the user with various posture and position information. For our given experiments, the system demonstrates high accuracy in identifying posture and position combined with a relatively inexpensive cost. For future work, the system can be further productized for mass consumption by using smaller sensors and acquisition device. Furthermore, long-distance wireless capability such as WiMax or LTE can be incorporated.

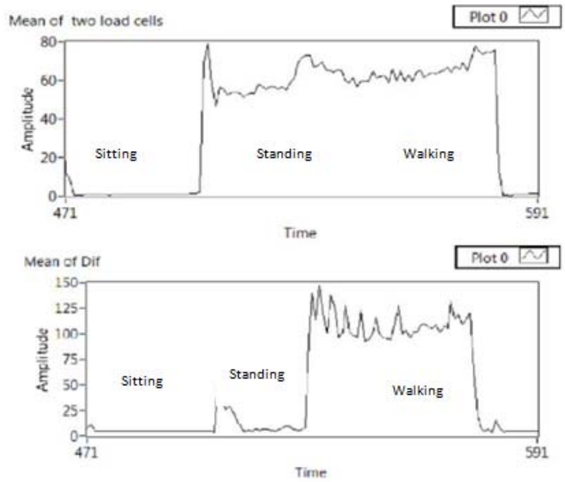

Figure 7. Strain Chart

VI. REFERENCES

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