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Sitting Posture Recognition for Computer Users using Smartphones and a Web Camera

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***Abstract*—This study developed models that automatically recognize proper / improper sitting postures using accelerometer readings from some human spinal points (thoracic, thoraco-lumbar and lumbar) through small, thin, and lightweight smartphones attached at those points, and by using a web camera which detects the upper body points' location and distances (chin, manubrium and acromion process). It also established relationships of human body frames and proper sitting posture. The models were developed by training some well-known classifiers such as KNN, SVM, MLP, and the RapidMiner's Decision Tree using the data collected from 60 participants of different gender and body frames. Decision Tree classifier demonstrated the most promising model performance with an accuracy of 89.83% and a kappa of 0.785 for the spinal posture, and an accuracy of 95.35% and a kappa of 0.907 for head and shoulder posture. Results also showed that there were relationships between body frame and sitting posture.**

Keywords — posture; gyroscope; spinal points; ergonomics; image processing

I. Introduction

Human posture reveals the alignment of the body, which requires equilibrium to keep a balanced and comfortable stance in any position. Improper posture causes the upper back to hunch or the lower back to arch too much [1]. Posture also affects productivity and health. According to Robertson et al. [2], Work-related MusculoSkeletal Disorders (WMSDs) among office workers with intensive computer use is already widespread. As evidence, Chavda et al. [3] evaluated the current practice of laptop computer and other computer-related health problems among college students in a tertiary care hospital and teaching medical college. They found out that the students' practice of laptop usage was ergonomically improper which causes various musculoskeletal problems (e.g. back pain, neck pain, etc.) among these medical students. Based on these studies, it is evident that there is a need to increase the awareness of proper sitting postures to improve the current practice and to reduce health problems among computer users.

This study aims to develop acceptable models that could recognize proper and improper sitting postures using accelerometer readings from the specific key points of the human spinal column such as the thoracic, thoraco-lumbar and lumbar through smartphones, and a built in web camera of a laptop for detecting upper body points such as the chin, manubrium and acromion process. This study also tries to establish the relationships between human body frame and sitting posture. Due to the unavailability of factory-made thin and lightweight dedicated accelerometers or gyroscopes, this study used three (3) small and lightweight mobile devices such as smartphones with gyro sensors, attached at the aforementioned spinal points of the subject through a customized girdle (see Fig. 1) to read the inclination of the said spinal points.

This study may provide opportunities for other researchers to develop systems that recognize not only proper/improper sitting posture, but for human body postures as a whole.

II. Related Works

This section discusses the relevant studies and literature that motivated the conduct of this research to contribute to the present knowledge on human posture.

Posture is the relative arrangement of the parts of a body. Good posture is that state of muscular and skeletal balance which protects the supporting body against injury or progressive deformity, irrespective of the attitude (erect, lying, sitting, and stooping) in which these structures are working or resting [4]. On the other hand, poor posture is a faulty relationship of the various parts of the body which produced increase strain on the supporting structures and in which there is less efficient balance of the body over its base support [4]. In addition, poor alignment of the head and shoulder may contribute to this bad body posture that may be seen to those people working in front of computers [5].

Poor posture disrupts the balance when everything is properly aligned, the joints and muscles in the back share the burden of supporting the body weight so as weight increases, the risk for Repetitive Stress Injuries (RSI) may also increase. As reported by the Cleveland Clinic, a force to work harder with a bad body posture may also increase the risk of sprains and strains, as well as, lower back pain. Arthritis may also be a result of a poor body posture because of the unwanted wear between the joints and ligaments [6].

Good posture notes that the joints, muscles and ligaments, as well as, the bones are properly aligned and can work as intended by the nature. It also means that the vital organs, as well, as the body system is in the right position and can function at its best efficiency. Good posture helps contribute to the normal over all functioning of the body system [6].

The ideal alignment of head and neck is one in which the head is well- balanced position that is maintained with minimal muscular effort. In side view, the line of reference coincides with the lobe of the ear, and the neck presents the normal anterior view. The head is not tilted forward or downward, and it is not tilted sideways or rotated. The chin is not retracted. Good alignment of the upper back is essential for the good alignment of head and neck; faulty alignment of the upper back adversely affects the alignment of the head and neck. If the upper back slumps into a rounded position when sitting or standing, a compensatory change will occur in the position of the head and neck.

For an aligned posture of the thoracic spine, it should curve slightly in a posterior direction. Just as the positions of the head and neck are affected by the position of the thoracic spine, so the thoracic spine is affected by the positions of the low back and pelvis. If a normally flexible individual assumes a position of lordosis of the low back (increased anterior view), the upper back tends to straighten, decreasing the normal posterior curve. On the other hand, habitual positions and repetitive activities may give rise to the development of a lordotic-kyphotic posture in which tends to compensate on the other. In a sway back posture, the position increased posterior curvature of the upper back compensates for a forward deviation of the pelvis.

Lastly, for the shoulder alignment, the side view line of reference passes midway through the joint. However, the position of the arm and the shoulder depends on the position of the scapulae and the upper back. In good alignment, the scapulae lie flat against the upper back, approximately between the second and seven thoracic vertebrae, and approximate four (4) inches apart (more or less depending on the size of the individual).

If the person suffer from a bad body posture, the overall health and total efficiency may be at risk because the long-term effects of poor posture can affect bodily systems (such as digestion, elimination, breathing, muscles, joints and ligaments), a person who has poor posture may often be tired or unable to work efficiently or move properly [6].

According to Mori et al [7], fifty percent (50%) of Americans who are working suffer from back pain since they always work with wrong posture, and is the second most common reason for them to visit a doctor. Twenty five percent (25%) of those with back pain suffer from a herniated disc, which may be caused by poor posture.

Cooper et al. [8], conducted a survey on computer usage and ergonomic risk factors among college students. Thirty percent (30%) of respondents who used desktop PCs and eighteen percent (18%) who used notebook PCs (NPCs) reported assuming awkward or uncomfortable postures “quite often” or “almost always”.

Another group of researchers [9] compared computer usage in college students and professional workers. The results showed that total reported computer use by graduate students (33.7 hours per week) was similar to that of professional workers (35.7 hours per week). Also, the propensity for continuously working at the computer (meaning the lack of breaks) correlated with the reported discomfort among the students. The similarities between the professional worker and college students computing hours, as well as their reported discomfort, suggests the need to implement some type of ergonomics intervention for the college student population.

The prevalence of MSS (musculoskeletal symptoms and disorders) among persons with frequent use of computer (3-5 h/day) ranges from forty percent (40%) among college students [10], fifty percent (50%) among new workers in the first year of the job, to over seventy percent (70%) of university staff and students [9].

In connection to these, Haruna et al. [5] developed a BITAIKA system that is visually understandable to its users. It monitors the posture using Kinect and multiple piezoelectric sensors. Kinect sensor captures the person’s lateral image and detects the head and middle position of the body. These sensors were connected to the computer and to give notifications to the user, a message will pop up to the screen.

The study of BITAIKA used 1-Nearest Neighbor (IB1), multilayer perceptron (MLP), and SVM classifiers. The results were IB1 (63.3% precision, 86.4% recall), MLP (72% precision, 81.8% recall) and SVM (80% precision and 72.7% recall). SVM shows the most stable result in terms of accuracy, precision and recall. The study conducted a prototype experiment to determine the effectiveness of the system and as a result, it was confirmed that the system effectively works as a posture adjustment system.

On the other hand, Claus et al. [11] determined if there is an ideal sitting posture using quantified surface spinal curves. It also examined whether subjects could imitate clinically ideal directions at thoraco-lumbar and lumbar regions of spinal curve. The tracking device recorded the 3-D position of each sensor attached to these points. 3D sensors were attached on these points and results showed that although subjects imitated postures with the same curve direction at these points, they still need to have feedback/manual facilitation.

According to the study that was conducted by Berner et al [12] from April- June 2013 in a tertiary care hospital and teaching medical college, current practice of laptop’s usage was ergonomically improper. Prolonged usage of improper posture has created various musculoskeletal problems among medical students. The participants were 100 students with age group 22-28 years old using a laptop computer.

Mean age of the students was 26 ± 1.4 years. Sixty (60) percent were male and forty (40) percent were female. Eighty five (85) percent of the students used laptop for more than one hour daily or alternate day but only half of those had a break during laptop’s usage.

Up to twenty (20) percent of the students suffered from one of the musculoskeletal problems every time when they worked with laptop computer. The students suffered frequently from various musculoskeletal health problems like eyes strain (30%), neck pain (15%), back pain (15%), shoulder and arms pain (10%), wrist and hand pain (35%), and headache (20%) after laptop’s usage. The information was gathered using a predesigned and content validated, self-reporting questionnaire of laptop ergonomics was used for data collection. The questionnaire accommodated three (3) sections of questions. The first section addressed personal profile of students. The second section was concerned with the practice of students for computing laptop. The third section was concerned with computer related health problems among students.

The insights and information that were gathered in these presented related literatures and studies motivated us to pursue this study.

III. Research Methodology

A. *Preparation*

1) *Participants:*

The participants in this study were sixty (60) volunteer students, comprising of thirty (30) female and thirty (30) male students of legal ages from higher educational institution in Valenzuela City, Philippines. Participants were pre-assessed by a Licensed Physical Therapist (PT) to ensure that each body frame in terms of height and wrist size [13] shown in Table I is well represented. And that each participant does not have pre-existing spinal conditions such as scoliosis and/or kyphosis.

TABLE I. Body Size Categories.

Gender	Height	Wrist Size	Category	No. of Participants
Female	5' 2" or less tall	< 5.5"	Small	5
		5.5" to 5.75"	Medium	5
		> 5.75"	Large	5
	5' 2" to 5' 5" tall	< 6"	Small	5
		6" to 6.25"	Medium	5
		> 6.25"	Large	5
Male	5'5" or less tall	< 6"	Small	5
		6" to 6.25 "	Medium	5
		> 6.25"	Large	5
	taller than 5' 5"	<6.25"	Small	5
		6.25" to 6.5"	Medium	5
		>6.5"	Large	5

2) *Data Gathering Tools:*

It is well known that android platform provides a hardware-based motion sensor (accelerometer and gyrometer). It captures the acceleration force along x, y and z axis including the gravity. Hence, to determine proper or improper spinal posture, we developed an Android-based mobile application that gets the accelerometer reading of the mobile device in terms of its inclination with respect to the vertical axis.

We then deployed this application in three (3) small, thin and light smartphones so that these phones will be the mediums in getting the inclinations (in degrees) of the three (3) human spinal points, namely: thoracic, thoraco-lumbar and lumbar. To ensure accurate readings on the spinal points, we customized an adjustable girdle (Fig. 1) to assure perfect contact of the smartphones on those spinal key points.

We also customized a PC-based server-side application through a web-service using Play Framework in Eclipse to capture the accelerometer (inclination) readings on those smartphones.

Fig. 1. The customized adjustable girdle.

Lastly, to determine proper head and shoulder posture, we developed a PC-based application using MATLAB to get the coordinates of some key points in the human upper body parts such as the chin, manubrium, left acromion, right acromion through simple image processing. However, to ensure more accurate data reading, the participants were asked to wear fitted sleeveless (Fig. 2a) or white T-shirt (Fig. 2b). When using T-shirt, the manubrium and left and right acromion were covered. So the PT placed distinct marks (e.g. red, green, blue for clarity) on the T-shirt to represent the areas of interest (Fig. 2b).

(a) (b)

Fig. 2. Upper body-parts key feature points.

B. *Data Gathering*

We gathered some demographic information from the volunteer participants through survey forms. These include the name (optional), age, gender, height, weight, and wrist size. We used some of these data to categorize the participants (Table I) and to compute their body mass index (BMI).

To collect the spinal posture data, we asked the participant to wear a customized girdle with the smartphones in it. The girdle was adjusted to ensure that the phones were properly attached at specific key points on the participant's spinal columns. The mobile applications were turned-on, ready to read accelerometer data. For the head and shoulder posture, the participant was asked to wear a fitted sleeveless or T-shirt (see Fig. 2). After which, the participant was asked to sit in front of the server (our laptop) in his/her preferred manner and work with our customized PC-based application, but ready to follow a command from the Physical Therapist. The laptop was adjusted so that the screen is at eye level (A) and an external keyboard and external mouse (B) were plugged-in so that the participant can type without strain (see Fig. 3). An adjustable chair was also used to support deep breathing and relaxed muscles.

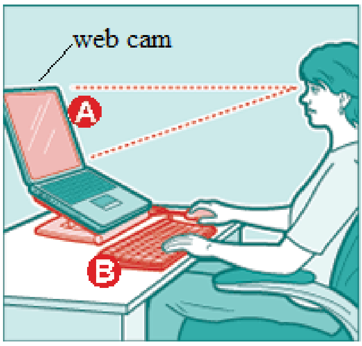

Fig. 3. Data gathering setup.

One PT observed the participant's lateral view while another PT observed the frontal view. On a command "Go" from the PT observing the lateral view, the participant must clicked a button on the PC-based application running in the laptop in order to capture and record the readings of the mobile applications and the x-y coordinates of the front upper body key points. There were nine (9) captures of proper and also nine (9) improper sitting positions. The PT arranged the participant's head, shoulder and/or back as the need arose, in order to capture the proper postures. To minimize bias in data capturing, the PTs allowed the participants to rest for a while.

C. Feature Extraction

There were several spinal features that were considered, including the head and shoulder features to recognize proper or improper posture. For the spinal features, we mapped the participant's demographics (gender, height, weight, the computed BMI, age, wrist size) with the corresponding spinal key points (inclinations of the thoracic, thoraco-lumbar, lumbar spines). The result is called the dataset for spinal posture recognition. For the head and shoulder features, we also mapped the participant's demographics with some computed distances, in pixels, between some front head and shoulder feature points. These include: the distances between the chin and the manubrium (ChinToManubrium) and the chin and the left or right shoulder (ChinToShoulder); the differences in X-axis of chin and manubrium (ChinXManX), as well the the left and right shoulders (AcrLXAcrRX); the difference in Y-axis of the left and right shoulders (AcrLYAcrRY); and the vertical distance (ChinXShoulderX), as well as the horizontal distance (ChinYShoulderY) between the chin and shoulder. The result is called the dataset for the head and shoulder posture recognition. Each dataset (spinal, and head and shoulder) were further divided into two (2) subsets, namely: the training sets which consist of ten (10) instances for every participant (3 participants per body frame), and the test sets which consist of ten (10) instances for every participant (2 participants for each body frame). The sources of the test sets were the first and fourth participants in each body frame.

D. Model Development and Analytics

By means of RapidMiner and by using each training set mentioned in the previous section, we developed models to recognize proper or improper sitting posture of these computer users by training some classifiers used by previous studies such as KNN, SVM, and MLP, plus a well-known classifier that can handle some nominal attributes and a nominal class called Decision Tree (DT). We also set the classifiers to Batch-X-Validation to allow student-level cross-validation on the models. Results showed that, for spinal posture recognition, the Decision Tree classifier provided the best model performance with an accuracy rate of 89.29 (see Fig. 4) and kappa statistic of 0.744 (see Fig. 5) when using gain ratio attribute criterion, a maximal depth of ten (10), a confidence of 0.25, a minimal gain of 0.1 and minimal leaf size of two (2). For the head and shoulder posture, the Decision Tree classifier also showed the best model performance with an accuracy rate of 97.71 (see Fig. 4) and a kappa statistic of 0.944 (see Fig. 5) when using information gain attribute criterion, a maximal depth of 10, a confidence of 0.25, a minimal gain of 0.1 and a minimal leaf size of 2.

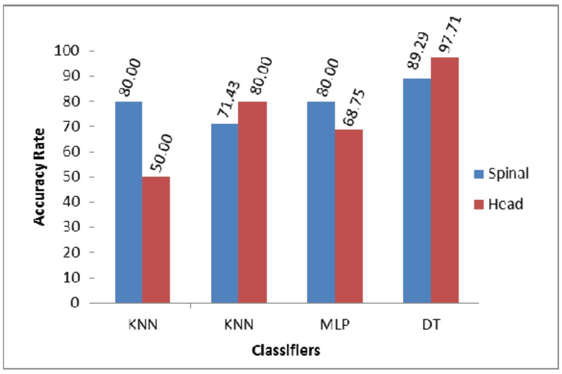

Fig. 4. Accuracy rates of the four (4) classifiers.

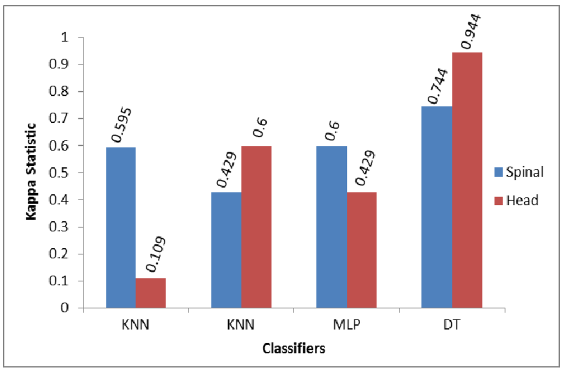

Fig. 5. Kappa statistic of the four (4) classifiers.

To establish the relationship between human body size and sitting posture, the unique paths from the root of the decision tree model to its leaves were analyzed and then transformed into rules. The rules to recognize proper and improper spinal posture is presented in Table II while the rules to recognize proper and improper head and shoulder posture is presented in Table III.

Also, we found out from the decision tree model, and as also shown in Table II, that the significant features for recognizing spinal posture are: the inclinations, with respect to the vertical axis, of the three spinal points (the thoracic, thoraco-lumbar, lumbar spines); the Gender, and the Body Mass Index (BMI) of the participant. On the other hand, the difference in X-axis of the chin and manubrium (ChinXManX), the difference in Y-axis of the left and right shoulders (AcrLYAcrRY); the distances between the chin and the manubrium (ChinToManubrium) and the chin and the left or right shoulder (ChinToShoulder); and the Body Mass Index (BMI) are the significant features in recognizing front head and shoulder posture (as shown also in Table 4). Since the Body Mass Index appeared in both models, it may be safe to conclude that the body size/frame plays a significant role in recognizing proper or improper sitting posture.

TABLE II. RULES FOR RECOGNIZING SPINAL POSTURE.

Most Likely	Rules
Proper	• IF ((thoracic >94.500) AND (thoraco-lumbar <= 108.500) AND (lumbar <=95) AND (Gender = 'M'))
	• IF ((75.500 < thoracic <= 94.500) AND (107.50 < thoraco-lumbar <= 108.50) AND (76.50 < lumbar <= 103.50) AND (BMI = "Underweight"))
	• IF ((75.500 < thoracic <= 94.500) AND (90.50 < thoraco-lumbar <= 107.50) AND (76.50 < lumbar <= 103.50))
	• IF ((75.500 < thoracic <= 94.500) AND (85.0 < thoraco-lumbar <= 90.50) AND (83.0 < lumbar <= 103.50))
Improper	• IF (thoracic <= 75.500)
	• IF ((thoracic > 75.500) AND (lumbar > 103.500))
	• IF ((thoracic > 75.500) AND (lumbar <= 103.500) AND (thoraco-lumbar > 108.500))
	• IF ((thoracic > 94.5) AND (thoraco-lumbar <= 108.5) AND (95.000 < lumbar <= 103.500))
	• IF ((thoracic >94.500) AND (thoraco-lumbar <= 108.500) AND (lumbar <=95) AND (Gender = 'F'))
	• IF ((75.500 < thoracic <= 94.500) AND (thoraco-lumbar <= 108.500) AND (lumbar <=76.500))
	• IF ((75.500 < thoracic <= 94.500) AND (thoraco-lumbar <= 86.00) AND (76.50 < lumbar <= 103.50))
	• IF ((75.500 < thoracic <= 94.500) AND (107.50 < thoraco-lumbar <= 108.50) AND (76.50 < lumbar <= 103.50) AND (BMI = "Normal"))
	• IF ((75.500 < thoracic <= 94.500) AND (85.0 < thoraco-lumbar <= 90.50) AND (76.50 < lumbar <= 83.0))

TABLE III. RULES FOR RECOGNIZING HEAD AND SHOULDER POSTURE.

Most Likely	Rules
Proper	• IF ((ChinXManX < 16.500) AND (AcrLYAcrRY <=2.5))
	• IF ((ChinXManX < 16.500) AND (AcrLYAcrRY >2.5 AND AcrLYAcrRY < =9.50) AND BMI = 'Obese"))
	• IF ((ChinXManX < =16.500) AND (AcrLYAcrRY <=25) AND (ChinToManubrium > 155. 5 AND ChinToManubrium<= 288.500) AND (ChinToShoulder >252.310))
Improper	• IF ((ChinXManX > 16) AND (AcrLYAcrRY > 9.5))
	• IF ((ChinXManX <= 16) AND (AcrLYAcrRY <=25) AND (ChinToManubrium <=155.500))
	• IF ((ChinXManX <=16) AND (AcrLYAcrRY >2.5 AND AcrLYAcrRY<= 9.50) AND (BMI = 'Underweight"))
	• IF ((ChinXManX <=16) AND (AcrLYAcrRY >25))
	• IF ((ChinXManX <= 16) AND (AcrLYAcrRY <=25) AND (ChinToManubrium > 155. 5 AND ChinToManubrium <=288) AND (ChinToShoulder <=252.310))
	• IF ((ChinXManX <= 16) AND (AcrLYAcrRY <=25) AND (ChinToManubrium >288.500))

E. Model Testing

To further evaluate the performance of each model generated by the Decision Tree classifier, these models again tested using the pre-labeled test sets defined in the previous section. Results showed that for spinal posture recognition, the overall model performance have an accuracy of 89.83% and a kappa of 0.785. Likewise, the ability of the model to recognize proper spinal posture is 92.36% while the ability to recognize improper spinal posture is 85.87% (see figures below).

For head and shoulder posture recognition, the accuracy rate of the model was 95.35% and the kappa is 0.907. Its ability to recognize proper head and shoulder posture is 90.77% while for improper head and shoulder posture is 100.00%.

These results imply that the models are quite acceptable since both models consistently providing high accuracy rate and kappa statistic.

F. Prototype Development and Testing

Since the results in model development, validation and testing were quite acceptable, the models were then subjected in a real-world test by embedding them in a prototype that recognizes proper or improper sitting postures. The prototype was built by enhancing our existing data gathering tools. That is, by adding other functionalities such as automatic feedback mechanism.

For spinal posture, the three (3) mobile devices and the server, which is our laptop, were connected on a same network using the Play Framework in Eclipse. Some necessary information were also entered in the mobile devices such as the

IP Address of the server, and the gender, height, weight and wrist size of the participant. After ensuring that each mobile device was correctly placed at each spinal point, then the server collects the information entered in the three (3) mobile devices at the same exact time. It checks and validates it through the developed model then shows whether the posture is proper or not.

For front head and shoulder posture, other information such as the weight, height, and gender about the participant were also entered in the prototype. The prototype also automatically turns on the web camera.

There were twelve (12) volunteer participants (separate from the original 60 participants) of different body frame categories in the prototype testing. During the tests, a PT stands at the front and another PT stands at the side of the participant and constantly observed the sitting posture. At a specified time, the server and the PTs report their observations simultaneously. Two (2) observations were done on each participant. Surprisingly, the report of the prototype was always the same with the PT's report. This implies 100% agreement between the PTs and the prototype.

IV. Conclusions And Recommendations

Through this study, we were able to develop models that automatically recognize proper / improper sitting postures using accelerometer readings from some human spinal points (thoracic, thoraco-lumbar and lumbar) through smartphones attached at those points, and by using a web camera which detects the upper body points' location and distances (chin, manubrium and acromion process). Also, the models show that the human body size/frame in terms of Body Mass Index (BMI) is significant in recognizing proper and improper sitting posture of computer users.

It was observed that the size and the weight of the mobile devices made the participants uncomfortable during the conduct of data gathering and prototype testing. Thus, the development of lightweight thin microchips with gyro sensors that may be easily attached to strategic points (i.e. thoracic, thoraco-lumbar and lumbar) along the spinal column is highly recommended.

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