Wearable Posture Identification System for Good Sitting Position

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***Abstract*—Every human spends most of their time remain seated especially students. A good posture during seated is important to determine the human health, while a bad posture during seated posture can lead to numerous diseases. This paper explained the design and development of wearable posture identification system using accelerometers to determine the good human posture in a seated position. Two accelerometers were used to determine the posture of an individual. The first accelerometer was placed on the human lumbar spine while the second accelerometer was placed on the human cervical spine. The calculation of the angle in determining the posture was processed using Arduino. There is three experiment was conducted: calibration test, performance measurement test and real-time analysis test. The calibration test was conducted to determine the percentage error of the accelerometer when compared with goniometer at static condition. The second experiment was conducted to determine the percentage error of between accelerometer and electrogoniometer at the dynamic condition. The third experiment was conducted to test the accelerometer in real life environment. The result showed that accelerometer has the percentage error less than 3% when compared to goniometer and electrogoniometer. This system can monitor and identify the good and bad sitting posture.**

***Index Terms*—Sitting Posture; Accelerometer; Goniometer; Electrogoniometer.**

I. INTRODUCTION

Human posture is defined as the way a person holds their body upright against the gravity while sitting, standing or walking [1]. A good posture is when we put minimum strain on the body muscle and ligament when walking, standing and sitting [2]. Human posture will be affected the most as they stay with the same posture for a longer period. Each individual will have different effects on their body if the prolonged posture is maintained. In daily human life, people are remaining seated for most of the time and estimated almost 13 hours of their day remain seated [3]. Thus, remaining a good body posture during sitting is very important to avoid back pain. The student is the most affected compared with the others when sitting as they remain seated between 19-90 minutes during a 90-minute double lesson. The average students remain seated in school more than 60 minutes. Remaining seated in a static condition for a long period of time without any disturbance or any movement can cause discomfort to the person.

There is three sitting condition that is the upright position, leaning forward and leaning backwards as shown in Figure 1. Leaning forward is when the student is writing and painting; while leaning backwards is when the students are reading and looking at the whiteboard. In recent studies, 57% of students were leaning forward, and another 43% is leaning backwards [4]. The posture of the human back must be maintained in good condition as a bad posture also will affect the spine condition. Students need to make sure their back posture is correct as their spine is still mild. Their spine can easily adapt to a bad posture if the posture is not corrected over a long period. Sitting in a long time with a bad back posture will affect the student spine condition as well can affect others things such as can increase stress level, doubles the risk of diabetes and can cause cardiovascular problems [5].

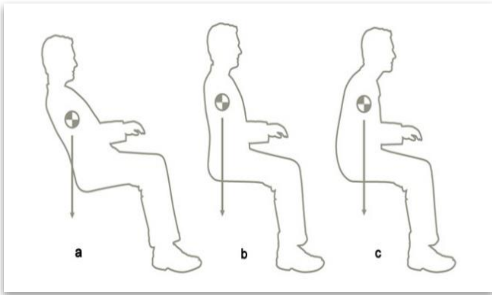

Figure 1: Sitting condition: a) leaning backward; b) upright; c) leaning forward [3].

The neck weight seen by the spine is dramatically increased when the head forward at varying degrees. Good posture is defined as ears aligned with the shoulders, and the shoulder blades retracted as Figure 2(b). As the head is tilted forward and backwards, it will increase the force on the cervical spine and lead to poor posture shown in Figure 2 (a) and (c). When the students seated in the school, they usually don't care about their neck posture. They spend an average of two to four hour a day with their head tilted over reading, and cumulatively this is about 700 -1400 hours a year of excess stresses seen about the cervical spine. Most of the students may spend an extra 5000 hours in poor posture. Although it is almost impossible to avoid these issues, individuals especially students should make an effort to maintain a neutral spine condition and to avoid spending hours each day hunched and leaning over [6]. Therefore, the wearable posture identification system for good sitting position is developed for monitoring and warning on students' posture. In this paper, this system will be analysed its performance and demonstrated in a real-time environment.

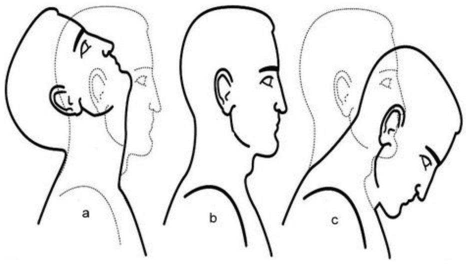

Figure 2: Neck condition: a) neck extension; b) normal; c) neck flexion [4].

II. LITERATURE REVIEW

Human spine consisting of 33 individual bones stacked all together. The spine is divided into five segments, as shown in Figure 3 (Cervical-7 vertebrae, Thoracic-12 vertebrae, Lumbar-5 vertebrae, Sacral-5 Vertebrae and Cocyx-4 vertebrae) [7]. The main function of the spine is to give the support for a human to do daily activities such as sitting and standing. The normal human spine will have a natural S-shaped curve. A good posture will ensure least amount of strain is placed on the human spine during body movement. The human neck also known as cervical part consists of seven vertebrae that are from C1 until C7, which have a great ability for flexion, extension and rotation. The main function of the cervical is to support head weight and protect the spinal cord. Thoracic is a mid-back region of the back body and consists of 12 vertebrae (T1-T12). The main function of the thoracic vertebrae is to hold the human rib cage for protecting the lungs and the human heart. The movement of the thoracic is limited compared to the cervical. Lumbar is a region at the lower back of the human spine (L1-L5). It functions as the weight support of the human body. The vertebrae of the lumbar are much larger than vertebrae at cervical and thoracic due to its function to absorb and bear the stress of sitting and carrying an object. Lumbar vertebrae are more flexible than the thoracic vertebrae due to lack of ribs in the lumbar region. Sacrum connects the spine with the hip bones (iliac). The entire five sacral vertebrae are fused together. The coccyx is the last part of the human spine and consists of four fused vertebrae to provide attachment for muscle and ligaments of the pelvic floor.

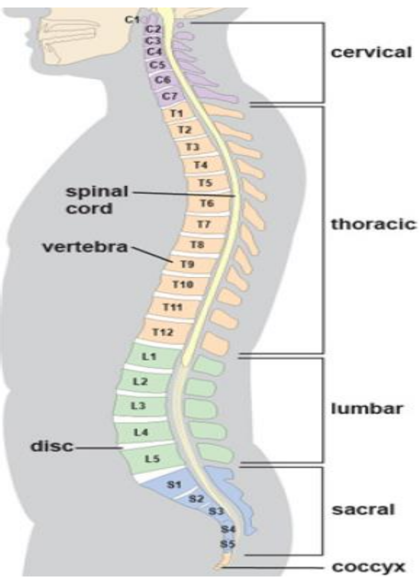

Figure 3: Five segments of the spinal column [20].

Human posture can be identifying through the motion (flexion, extension and rotation). Human posture can be analyzed either by using direct observation, using video computer analysis or different types of sensors such as strain sensor, inclinometer sensor [8]–[10], accelerometer sensor [6], [11], [12], Kinect sensor [13]–[15], goniometer [16]–[20], electrogoniometer and many more. Different sensors have their application and some of the sensor focusing on the effect of posture regarding discomfort, some of the muscle work and some on relations between body parts [5].

A goniometer is a device that is used by a doctor or physical therapy to measure the range of motion (ROM) around a joint in the body. A joint's ROM is measured by the number of degrees from the starting position of a segment to its position at the end of its full movement. For the cervical ROM measurement, the subjects were placed in a straight-back chair with their feet on the floor. To stabilise the trunk, the subjects were instructed to seat with the trunk erect and supported on the back of the chair, with hip and knee was in 90 degrees flexion and feet were rested on the ground. However, this method is an inadequate method of eliminating lateral flexion of the trunk during cervical ROM measurement [20]. However, a goniometer is the manual assessment and unable to store data. Thus, electrogoniometer was invented to have precise and accurate evaluation compare to two manual protractors. The electrogoniometer shows a high precision by ±0.1° for all different ROM angles. It can evaluate six types of movement directions and five different angles for a given movement direction. The obtained electrical signals are calibrated, and the data of movement angles is presented in degree [21]. However, the accuracy of the device is less than accepted [22].

Thus, an accelerometer sensor is used in this paper to develop a wearable posture identification system. Accelerometer sensor is a dynamic device that can measure in one, two or three orthogonal axes. AB. Crane .et .al [6] used four LilyPad 3-axis accelerometers and a compatible Bluetooth modem would corporate with LilyPadArduino. The four accelerometers will be placed at the reference point coinciding with important vertebral locations (C5, T2, L1, and L5). The vertebral location was chosen to facilitate the calculation of the three primary spinal angles (thoracic kyphosis, cervical lordosis, and lumbar lordosis). The accelerometer will draw a very low supply current that is 350μA. The current is low than the threshold for the human perception. The negative feedback is it failed to measure cervical or thoracic spinal posture [6]. M. Xu .et .al [11] used eight accelerometers placed on the four limbs (hands and legs) and an accelerometer placed on the torso to determine human posture. The relative angle between the limb and torso can be represented the relative angle between the accelerometer on the torso and the limb. The nine angle values can be obtained by converting the Euclidean coordinate system to Euler angle coordinate system for each of the accelerometer reading. When the subject is stationary, accelerometer only detects the acceleration due to the earth gravity. Used of gyroscopes will provide extra additional information but it will consume more power and caused power drain [23].

Some accelerometer-based prototypes were developed to monitor human posture. However there are bulky and complex with much instrumentation on the body. In this paper, we design and develop a small and portable wearable system for daily monitoring human sitting posture.

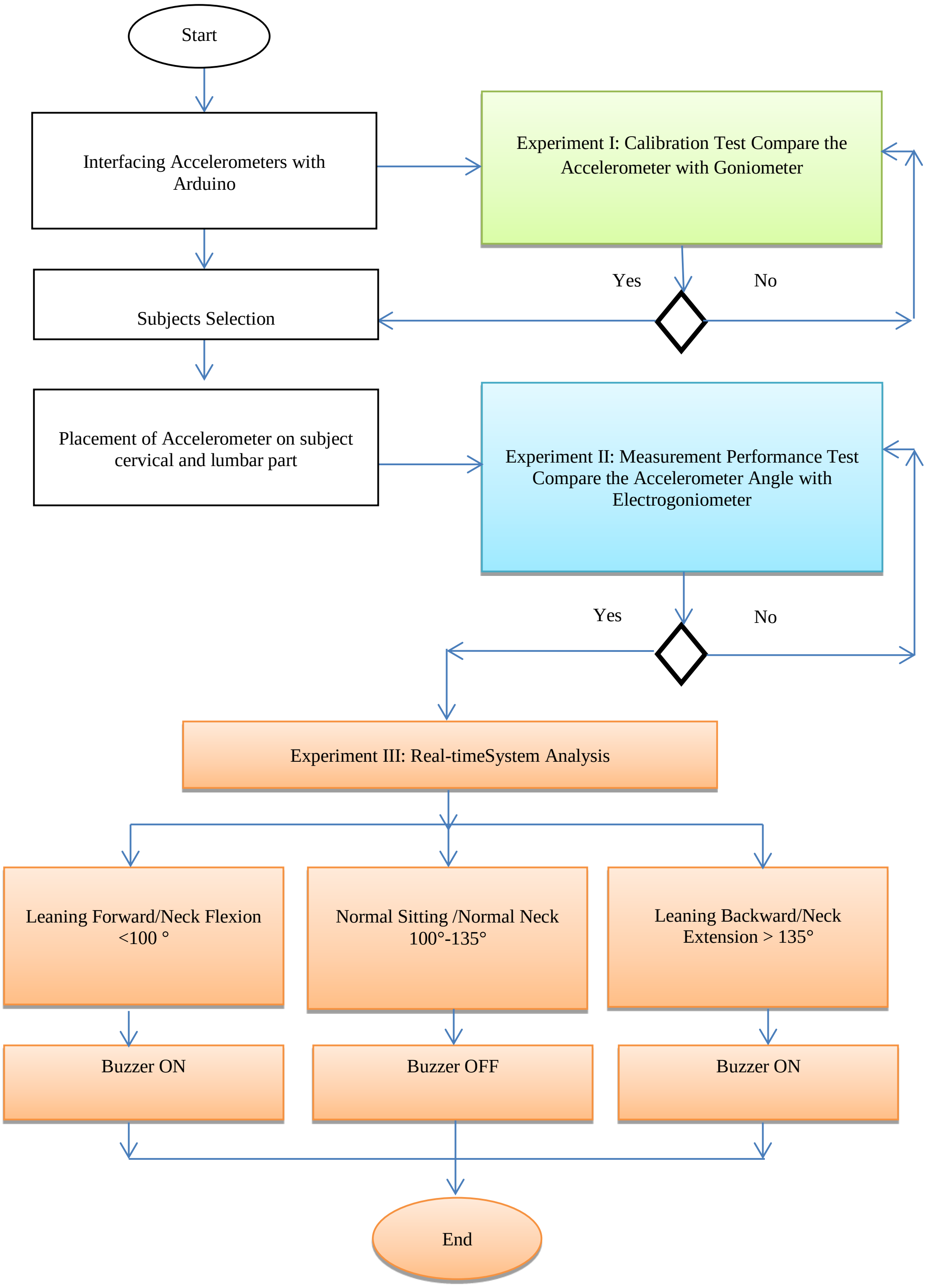

Figure 4: Flowchart of design and development experiment.

III. Development of Wearable System

A wearable monitoring sitting posture system was developed by using two ADXL 335 accelerometers and an Arduino UNO microcontroller. The two accelerometers were placed on cervical spine (neck) and lumbar spine (back) for flexion and extension measurements. The good posture defined as ears aligned with the shoulders blades, the posture of the head especially the neck should be constantly same with the posture of the lumbar spine. The increment of every angle flexion and extension of the neck will increase the weight of the head and directly increase the stress on the cervical spine and causes neck pain [4]. The lumbar spine is where the back pain occurs due to most of the strain is placed. The lumbar spine also experienced more motion compared with thoracic spine and most likely to injured if the posture is not correct [17]. The wearable monitoring sitting posture system was developed by interfacing the accelerometers with the Arduino Integrated Development Environment (IDE) are streamed through wireless transmission to a portable computer. The design and development experiment procedures are shown in Figure 4.

The accelerometer sensor must be utilised to get the desired angle for the process of posture detection. The angle between the trunk and neck were calculated by Equation (1) and (2).

$$\frac{A_{X,OUT}}{A_{Y,OUT}} = \frac{1g \times \sin\theta}{1g \times \cos\theta} = \tan\theta \tag{1}$$

$$\theta = \tan^{-1}\left(\frac{A_{X,OUT}}{A_{Y,OUT}}\right) + 180^{\circ} \tag{2}$$

where: $A_{X,OUT}$ =Output acceleration for X-axis.
$A_{Y,OUT}$ =Output acceleration for Y-axis.
θ = Inclination angle in radians.

Equation (1) shows the mathematical equation for the accelerometer to convert acceleration data to gravity. The inclination angle of the accelerometer is based on the acceleration output of the accelerometer. Thus, the measured acceleration is converted to an inclination angle by computing the inverse sine of the x-axis and the inverse cosine of the y-axis. Due to the inclination angle fall in the Quadrant II, so operand Quadrant II is negative, a value of 180° should be added to the result of the calculation when the angle is in that quadrant formulated at Equation (2). The inclination angle values will be used for further step for the detection of the good and bad posture.

IV. Results and Discussions

The performance of the developed wearable system was examined using three experiments which are an experiment I, experiment II and experiment III.

A. Experiment I: Calibration Test

In this experiment, the calibration test where the comparison between accelerometer and goniometer is made. In this test, a goniometer is used as a reference for the accelerometer. The experiment is conducted as to find the percentage error of the accelerometer from a fixed goniometer (referred as static data in angle). An accelerometer is placed on the movable arm with varied different angles as in Figure 5. The goniometer is fixed into 90° to 140° with an increment of 10°. There are two accelerometers were attached to the goniometer and the data being recorded. Each accelerometer reading was recorded five times for each degree of a goniometer. The data are recorded in the range of two seconds per data.

Figure 5: Goniometer with Accelerometer.

Then, the percentage error for each degree of the accelerometer concerning goniometer is calculated and shown in Figure 6. The results for both accelerometers are almost identical to the theoretical value of the goniometer. The smallest error of accelerometers is 0.04%, while the highest error is only 2.72%. This indicates that accelerometer gives a high accuracy value when compared with the static goniometer. The error that occurs from the accelerometer may occur due to the noise from the surrounding. The accelerometer is a very sensitive sensor that can easily react to any disturbance that occurs.

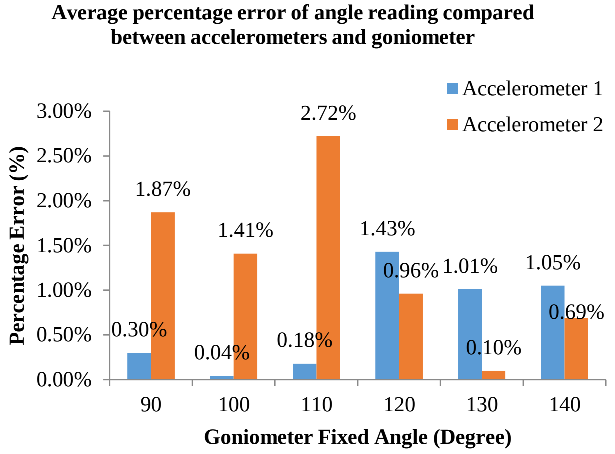

Figure 6: Average percentage error of angle reading compared to accelerometers and goniometer.

B. Experiment II: Measurement Performance Test

Experiment II is the measurement performance where the comparison of accelerometer data with electrogoniometer is conducted. The experiment is conducted by using three subjects to find the error between accelerometer and electrogoniometer. The three subjects in age (22 – 23-year-old), weight (64 – 68 kg), height (1.61 – 1.70 m) and Body Mass Index (BMI) in the normal range (23.5 - 24.7 kg/m2). The BMI of each of the subjects is important in maintaining the accuracy and reliability of the data. The experiment protocol is same for all the three subjects as shown in Figure 7. The subjects need to sit in a normal posture from the start of the experiment until at 20 seconds. From 20 seconds to 24 seconds, the subjects are asked to take the mobile phone that is placed in front of them. During the normal posture, the subjects are asked to read short stories on the computer. This is to replicate the posture of students when they look at the slides during lecture time. The posture transition from normal posture to leaning forward can be used to determine the error of accelerometer. The experiment is designed as a dynamic movement.

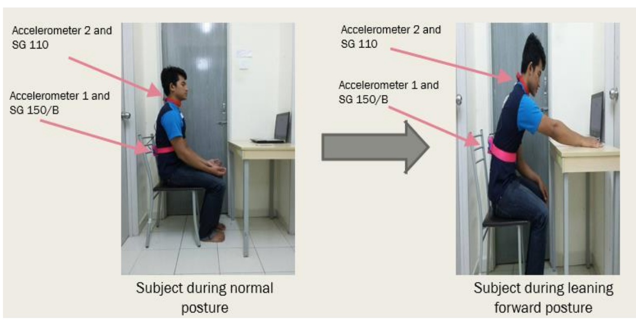

Figure 7: Subject posture with accelerometer and electrogoniometer.

Accelerometer 1 of the first subject that is placed on lumbar spine has an error of 0.97% when compared with electrogoniometer while the Accelerometer 2 has an error of

0.37%. The second subject has an error of 0.30% for the Accelerometer 1 and an error of 0.26% for the Accelerometer 2. The third subject has an error of 0.18% for the Accelerometer 1, and the Accelerometer 2 has an error of 0.42%. The relationship of the accelerometer to electrogoniometer placed on lumbar and cervical spine give a very small error of 0.48% and 0.35% as in Figure 8 and 9. The error may be due to the placement of accelerometer and electrogoniometer on the lumbar, and cervical spine is not attached well to the subjects' body. The movement and deviation of angle during posture transition may cause some errors.

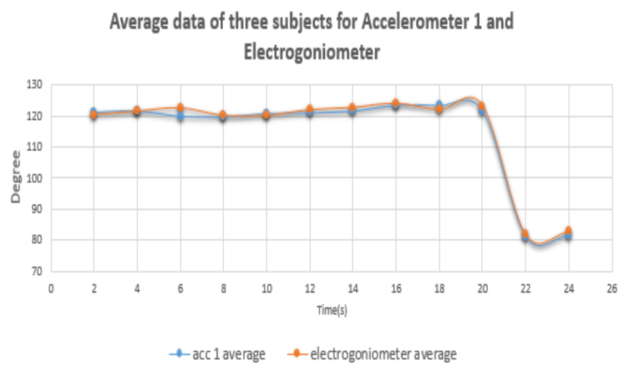

Figure 8: Electrogoniometer and Accelerometer 1.

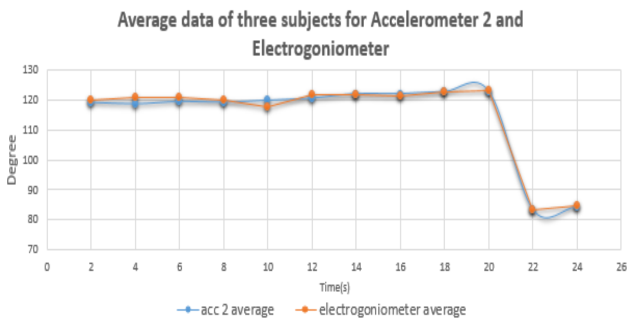

Figure 9: Electrogoniometer and Accelerometer 2.

C. *Experiment III: Real-time Analysis Test*

Experiment III is to investigate the ability of the system to perform detection of sitting posture in the real environment. The posture of the subjects during sitting posture is examined using our developed system as in Figure 9. The subjects performed several tasks, and the data is recorded. The buzzer that is equipped with the system will ring as the condition of the posture of the cervical, and lumbar spine is not in the range of 100° to 135° concerning Y-axis. The range from 100° to 135° is the best range for sitting posture [24]. This range gives less strain on the spinal disks, which is the more relaxed sitting position. Three subjects are selected in this experiment with age (21 - 28-year-old), height (1.58 – 1.70 m), and weight (50 – 67 kg). The BMI of each subject is in the normal range (18.5 kg/m2 to 24.9kg/m2) to ensure the data that are collected is reliable and accurate.

Firstly, subjects were asked to seat in leaning forward posture for the first 30 seconds of the experiment. Then, the subject's seat in normal posture for the next 30 seconds. For the last 30 seconds, the subjects are asked to make their sitting posture in leaning backwards condition as in Figure 10. The buzzer installed in the system would ring as the accelerometer angle is not in normal posture. Thus, as the subject's seat in leaning backwards and leaning forward posture, the buzzer will continuously ring until the subjects adjust their posture to make sure the cervical and lumbar spine are in normal condition.

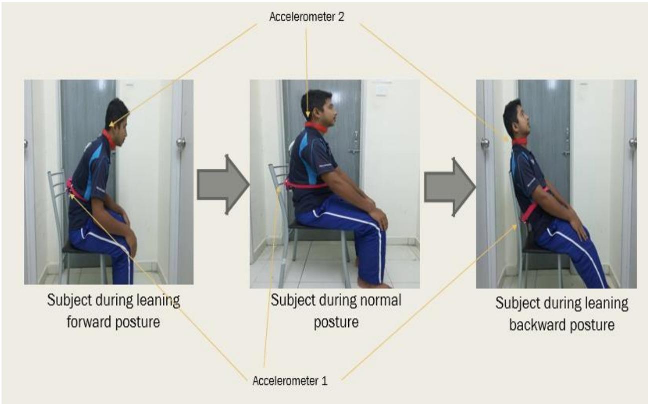

Figure 10: Subject posture with accelerometer system.

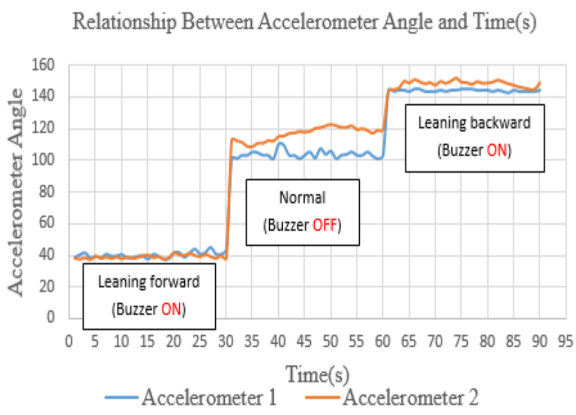

Figure 11: Subject posture with accelerometer system.

The spikes in Figure 11 show the movement of the subjects during the experiment. Every movement by the subjects will cause the increasing and decrease of the graph. Besides that, Figure 11proved that the system is suitable for the dynamic movement of the subjects and the system is functioning well in real life environment.

Overall, the developed wearable monitoring sitting posture system using the identification of the posture is successfully built and fully functional. Experiment I shows that the accelerometer is suitable for the static data; while Experiment II shows that the accelerometer is suitable for the dynamic data. Two experiments give a small percentage error with good performance for accelerometers when compared with a goniometer and with electrogoniometer in the fixed reference and the applied human motion condition. The small error occurred may cause the inaccurate placement of the accelerometer or may cause due noise from the surrounding that will affect the data that are being recorded. For the Real-time analysis (Experiment III), the wearable monitoring sitting position system by using accelerometer is proven to be functioning well in the real environment. The changes of posture from the subject can be detected accurately by the system.

The accelerometer in system mainly focused on the y-axis, which is the leaning forward, normal posture, leaning backwards, neck flexion, neck normal and neck extension are being calculated based on the y-axis. However, the experiment did not focus on the rotational movement. Some efforts can be made to improve the posture detection in x, y, and z-axis. The data can be more reliable for the posture detection.

V. Conclusion

The portable and wearable posture identification system for good sitting position is developed for monitoring and warning on students' sitting posture. This system is successfully built with accelerometer percentage error less than 3% when compared with a static angle of a goniometer. For the performance measurement test, the accelerometer 1 (Lumbar part) and accelerometer 2 (cervical part) give a small error of 0.48% and 0.35%, respectively. Moreover, our system is able to perform real-time analysis on monitoring the subjects' sitting posture. However, our system only focused on the y-axis. So in future, a better performance of the system can be done by including the x, y, and z-axis in determine good and bad seat posture. Furthermore, others technologies also can be implemented with the system such as inclinometer and gyroscope. The enhancement of the system can provide new methods in detecting seating posture. The new system can works more perfectly with the combination of the sensors. Besides, the system also can be made to work as a wireless communication with the mobile system which gives more flexibility to the users.

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