The development of a wearable biofeedback trainer to increase quality of sitting posture

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Abstract. In this paper, we design wearable devices that can monitor and provide voice and vibration feedback have been developed to change poor sitting positions. Abnormal posture has been shown to cause functional impairment in quality of life. This symptom is caused by the activity of sitting in a hunched position that is too long for years, thus permanently changing the shape of the back and the deterioration of joint function in the spine of the back. Previous research has been conducted on wearable devices to monitor the slope angle of the spine. but the system is still fairly simple because the system used is not directly integrated with media monitoring. In this study developed wearable devices using biofeedback trainer techniques to change bad habits when sitting in a hunched position so that the tool will provide a feedback to rearrange the position of the body by force into an upright position and the system will be integrated with the mobile application using Bluetooth. The results show that this wearable device can measure the slope angle of 0° to 90° with an average error of 0.42° and can improve the quality of sitting posture.

1. Introduction

Body posture with spinal disorders has been shown to cause the functional decline in quality of life [1]. Health disorder symptoms subjective and objective include lethargy, drowsiness, dizziness, lack of concentration, decreased level of alertness, and decrease the passion for work. This health symptom is caused by the passive activity which is sitting too long with the condition of the spine bent. Sitting for a long time will cause boredom and back pain so that it can cause health problems [2]. A chiropractic expert, states that more than 80% of neck and back problems are the result of muscle aches due to years of poor posture that can permanently change the shape of the shoulders and deterioration of joint function in the spine [3]. This is also evidenced by the results of research in the United Kingdom which states that one-third of the adult population with a total of 17.3 million experience back pain [4].

This study will analyze and monitor body posture using IMU sensors based on the author [5]–[8]. Using biofeedback technique by measuring the slope angle of the spine on the back which later the value of the sensor will be visualized on Android-based smartphone devices and processed into medical records to change bad habits when sitting. The process of continuous measurement and evaluation is very important for patients because it helps them to analyze their own performance to be motivated to do better [9].

2. Related work

Systems for monitoring sitting postures have been developed using various architectures. similar to the approach we developed, S. Bei et al. [10] using a depth sensor to detect a bad sitting posture so as to protect eyesight and prevent cervical spondylosis. Y.-R. Huang et al. [11] utilizing the force sensor is applied to the seat for collecting and analyzing information sitting posture. S. Ma et al. [12] using a single 3-axis accelerometer on the MPU6050 sensor mounted on the back of the neck to certify 5 types of sitting postures from 6 volunteers who have no spinal disorders. A. Petropoulos et al. [13] designing
real-time sitting posture monitoring by using two 6 DoF IMUs that are installed on the upper and lower spine which will be the value of the accelerometer and gyroscope will be sent through the BLE communication line and processed on the smartphone. E. Lou et al. [14] develop smart garments to improve children's posture by using two accelerometer sensors placed in the spine position which can later provide feedback in the form of vibrations in order to restore normal posture position.

3. Materials and methods
The system that will be designed aims to retrieve data on the slope angle of the spine, designed using the values obtained from the accelerometer and gyro which can be used as a measuring instrument for the backbone by utilizing measurements of gravitational acceleration and angular acceleration on the 3-axis accelerometer and 3-axis gyroscopes. The output value obtained from the accelerometer and gyro will be processed through the I2C line on Arduino nano. Sensitivity value on the accelerometer sensor uses ± 8g and the sensor gyroscope is ± 250° / s. Arduino I / O pins, there is a buzzer and vibrator motor which aims to provide feedback in the form of sound and vibration when the tilt angle exceeds the threshold value. The LED is used as a notifies for the start/stop button and the mode button. Connected the BLE HM-10 module through the UART line as a wireless communication path that will be integrated with Android-based smartphone devices. All hardware devices supplied using a voltage of 3.3V obtained from Li-ion rechargeable battery 3.7V done step-up into a 5V 0.5A. Applications on smartphones are used to process angle values into visual data and will also be processed into medical records. The system block diagram of the wearable device is shown in Figure 1.

![Figure 1. Wearable device system block diagram.](image)

3.1. Design process
Wearable devices are designed to be placed on a corset back that is easy to combine with electronic devices by means of sewing. In the corset will be installed microcontroller, 6-axis IMU, feedback, notifies, and Bluetooth communication lines as shown in figure 2 (a). The 6-axis IMU (MPU 6050) is selected because there an accelerometer and gyroscope sensor one module and can be run using low power. Estimated placement of the tilt sensor will be placed in the position of the T4 to the T6 thoracic section of the spine as shown in figure 2 (b).
3.2. Angle calculation algorithm
To get the slope angle value, MPU6050 is connected to I2C communication with a default frequency of 400k Hz on Arduino nano. In I2C communication, Arduino nano will set as master and the MPU6050 set as slave. The configuration used for accelerometer vulnerable value is ± 8g which has a vulnerability value of 4096 LSB / g and the vulnerable value gyro is ± 250 deg / s which has a vulnerability value of 131 LSB / sec[15]. Sensor testing is carried out in two conditions, namely conditions at idle position and rotating condition. When the condition is idle, it aims to know the offset value of a sensor that can be used to increase the accuracy of sensor readings.

\[dataX = dataX - dataX_{off}\]  
\[dataY = dataY - dataY_{off}\]  
\[dataZ = dataZ + (dataZ - dataZ_{off})\]

When the condition moves, aims to find out how fast the angle changes occur by combining the gyro data.

### Table 1. Raw value accelerometer on MPU6050

| No(n) | X   | Y   | Z   |
|-------|-----|-----|-----|
| 1     | -10 | -29 | 3853|
| 2     | 15  | -30 | 3852|
| 3     | -11 | -33 | 3863|
| ...   | ... | ... | ... |
| 498   | -38 | -26 | 3862|
| 499   | 6   | -24 | 3872|
| 500   | -38 | -26 | 3862|
| x     | -22 | -31 | 3856|

The placement of the sensor in a still condition can also be used as an accelerometer. If the MPU6050 is placed perpendicular to the direction of gravity of the earth, then the data will begin to get raw data. To increase the accuracy of the sensor, it can be done by making all the values of the force vector x and y become 0, while the z strategy is worth 4096. To display the serial raw communication data with a baud rate speed of 9600 from Arduino nano. The data to be used will be analyzed and used on average to find out the offset value in the raw data. The accelerometer value in MPU6050 is shown in Table 1.
In theory, if the sensor is placed with the position of the vector \( x = 90 \, ^\circ, \, y = 90 \, ^\circ \), and \( z = 0 \, ^\circ \), then the value of the axis \( x = 0, \, y = 0 \), and \( z = 4096 \). The values in Table 1 can be used as sensor calibration. This value will be an offset value for raw data.

\[
dataX = (-22) - (-22) = 0
\]
\[
dataY = (-31) - (-31) = 0
\]
\[
dataZ = 3856 + 240 = 4096
\]

### Table 2. Gravity Acceleration value on MPU6050 accelerometer.

| No | Vector Position (°) | Acceleration Gravity value (g) |
|----|---------------------|--------------------------------|
|    | \( \theta \) | \( \psi \) | \( \phi \) | X | Y | Z |
| 1  | 90 | 90 | 0 | -0.01 | -0.01 | 0.94 |
| 2  | 90 | 0  | 90 | 0.07  | 1.02 | -0.04 |
| 3  | 0  | 90 | 90 | 1.05  | 0.02 | -0.01 |

The reality is that the offset value for each axis is very rarely approaching a value of 0, this is due to the amount of noise in the hardware and interference from the environment at the time of testing. Furthermore, changing the value of raw data into gravity with a unit of g. Testing is done by placing the sensor parallel to the water pass. In theory, the results of the gravitational value that will be obtained when parallel to the direction of gravity of the earth is 1g. Whereas if it is perpendicular to the direction of gravity of the earth, then the sensor reading will produce a value close to 0g. The position of the vector is divided into three, namely \( \theta \), \( \psi \), and \( \phi \). On the x, y, and z-axes it is close to 0g and 1g but rarely gets the exact value in 0g and 1g due to the amount of noise from the sensor itself or when placing it on the water pass shown in table 2. After obtaining the gravitational acceleration value, we can determine the angular values \( \theta \), \( \psi \), and \( \phi \). However, in this design using the value of roll \( \theta \) and pitch \( \psi \). Gravity acceleration is a vector value that has direction and unit so that it can produce angular values from vector quantities using this tilt angle equation[16].

\[
\theta = \tan^{-1} \frac{-0.01}{0.94} = -0.009 \text{ rad} = -0.57^\circ
\]
\[
\psi = \tan^{-1} \frac{-0.01}{\sqrt{-0.01^2 + 0.94^2}} = -0.009 \text{ rad} = -0.57^\circ
\]

### 3.3. Application Interface

![Figure 4. Interface design.](image)

![Figure 5. Visual feedback when motion is over a range.](image)
The Android mobile application is created to display the value of the slope angle. Shown in Figure 3 the appearance of the animation will change if the angle exceeds the normal angle. The threshold value on the application applied is <79º following the lowest value from the normal posture angle[1]. The application can change the system mode on the wearable device to observation mode and standby mode. Observation mode is a curvature angle measurement mode without using feedback. Standby mode is a measurement mode of curvature angle values using feedback.

4. Results and discussions
To get accurate values, the angle value obtained from the wearable device is tested and how to compare the actual angle of protractor 10 times. Figure 4 shows that wearable devices can take an angle value of 0º - 90º with an average error of 0.42º.

### Table 5. Testing of volunteers.

| ID | Age | Average Angular tilt angle | Result(º) |
|----|-----|-----------------------------|-----------|
|    |     | Observation Mode (º) | Standby Mode (º) |          |
| 01 | 23  | 75.16                       | 79.66 | 4.5 |
| 02 | 23  | 70.33                       | 81.58 | 11.25 |
| 03 | 22  | 70.39                       | 80.47 | 10.08 |
| 04 | 22  | 67.23                       | 80.85 | 13.62 |
| 05 | 23  | 67.75                       | 81.59 | 13.84 |
| 06 | 22  | 59.08                       | 80.04 | 20.96 |
| 07 | 23  | 67.27                       | 83.76 | 16.49 |
| 08 | 23  | 82.54                       | 84.47 | 1.93 |
| 09 | 22  | 71.09                       | 81.14 | 10.05 |
| 10 | 22  | 79.31                       | 81.55 | 2.24 |
| 11 | 23  | 73.11                       | 85.00 | 11.89 |
| 12 | 23  | 67.32                       | 82.13 | 14.81 |
| 13 | 23  | 77.27                       | 82.47 | 5.2 |
| 14 | 22  | 75.16                       | 81.13 | 5.96 |
| 15 | 21  | 79.36                       | 84.98 | 5.62 |
| 16 | 24  | 70.92                       | 82.83 | 11.91 |
| 17 | 25  | 76.50                       | 83.59 | 7.09 |
| 18 | 21  | 74.47                       | 82.02 | 7.55 |
| 19 | 23  | 71.41                       | 81.71 | 10.3 |
| 20 | 20  | 75.21                       | 84.07 | 8.86 |
| 21 | 21  | 64.14                       | 81.15 | 17.01 |
| 22 | 23  | 71.56                       | 82.31 | 10.75 |
| 23 | 24  | 69.61                       | 81.82 | 12.21 |
| 24 | 24  | 72.48                       | 88.01 | 15.48 |
| 25 | 25  | 75.72                       | 81.63 | 5.91 |
| 26 | 23  | 72.89                       | 84.73 | 11.84 |
| 27 | 23  | 77.63                       | 85.67 | 8.04 |
| 28 | 23  | 74.16                       | 84.19 | 10.03 |
| 29 | 22  | 78.84                       | 83.82 | 4.96 |
| 30 | 23  | 77.36                       | 85.09 | 7.36 |
| \(\bar{x}\) | 72.84 | 82.78 | 9.92 |
Figure 6. Comparison of protractors.

Clinical trial testing was conducted on 30 volunteers, volunteer aged 20-25 years and daily activities sitting long in front of the computer will be tested using a wearable device which is done twice in the observation mode and also standby mode for 15 minutes at each stage. The threshold value given is <79º because the data of the spinal curvature of the horizontal harness in the normal posture is equal to 89.88º[1]. The test is intended to determine the increase in the average curvature angle after using wearable devices. The increased value is obtained from the comparison between the average angle values in the obsession mode with the average angle values in standby mode. Table 5 shows the results obtained in the volunteer test. The average yield of the spine curvature in the observation mode is 72.84º and the average spinal curvature angle in standby mode is 82.78º. It shows that there is an increase in the angle of curvature in the spine of 9.92º.

5. Conclusion

In this paper, we design a wearable device that can monitor your posture while sitting and can both provide feedback to remind the subject in order to maintain a sitting position is more balanced. The results show that this wearable device can measure the slope angle of 0º to 90º with an error of 0.42º and can improve the quality of sitting posture. The long-term effects of this wearable device are still under-investigated. In further research, we will add sensors at several points of the body to obtain more accurate laboratory tests in order to identify disorders such as lordosis and scoliosis, consultation with a hostage in the framework of striped bone therapy.

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