A LOW POWER ACCELEROMETER USED TO IMPROVE POSTURE

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ABSTRACT

A monitoring system for training people to improve posture has been developed. The prototype system consists of one accelerometer, a low–powered 16-bit microcontroller, RAM, real time clock and battery. This prototype device was used to investigate its feasibility of using accelerometers to monitor human posture. A subject who had kyphosis (round back) for many years wore the system for two days. The system provided feedback to the subject only on the second day. By comparing the data collected on both days, we found that the system was able to detect postural changes and alert the subject to improve his posture.

1. INTRODUCTION

Spinal deformities cause trunk rotation and sometimes creates an unacceptable appearance and back pain. Physical therapy and exercise are two common methods used by patients to stretch and strengthen their muscles in an attempt to reduce pain. Brace treatment is the most common non-surgical method to treat one type of spinal deformities. Brace treatment is thought to rely on either the mechanical support by a brace (passive component) or by pulling the body away from pressure sites imposed by the brace (active component) [1]. In the passive case, true forces imposed by the braces on the trunk are considered the key to successful treatment. In the active case, the brace simply provides a reference used by the patient to react against; it is the self- muscular control that treats scoliosis. A technique described by Schroth *et al.* [2] called "rotational breathing" attempts to actively correct body shape. This technique reminds the patient to create the opposite appearance to what the scoliotic body looks like. For example, if one side of the ribs has sunk inwards and downward, patients will try to move the ribs outside and upwards when they breathe in. Weiss *et al.* [3] suggested that Schroth's method is suitable for preventation and treatment of secondary functional impairment as well as for treatment of scoliosis related pain. Another group of researchers, Dworkin *et al.* [4], suggested that behavioral principles and therapeutic theory help scoliotic children correct their spinal deformities as well as cosmetic appearances. Dworkin's group used the apparatus called "Micro-Straight" to treat children with scoliosis. The micro-straight detects the length of the trunk and compares it to a pre-set value. If the length of the trunk is different from the preset value and lasts longer than 20 seconds, a beep tone will alert the patient to correct the posture. The results presented by Dworkin *et al.* showed that this approach was very successful in achieving improved posture. However, the drawback of the device is uncomfortable to wear.

Both treatment approaches rely less on mechanical correction, and more on providing appropriate feedback to the wearer. These studies suggest that patients may be able to transfer the learned corrected posture to a long-term improvement of trunk deformity. The mechanism for this may be that continuous muscle training results in a re-education of the scoliotic posture into a more balanced posture. Furthermore, El-Sayyad *et al.* [5] also showed that exercise alone can decrease the curvature of the spine.

Many methods for posture measurement have been developed, including goniometry, photogrammetry, optoelectric analysis, video analysis and sonic analysis. The principles of these methods have been summarized in Hsiao and Keyserling [6]. These methods have been widely used in the fields of orthopaedics and biomechanics. However, most of them have the following disadvantages:

i) a laboratory environment is required,
ii) technicians are necessary to record data,
iii) analysis time is long, and
iv) set up charge is expensive.

Commercially available [7], gyroscope and magnetic sensors, are well-known devices to measure tilt angle. They are small and light-weight, but they are very sensitive to mechanical vibration and thus are not suitable for measuring posture during daily activities. Kato *et al.* [8] developed a photoelectric inclination sensor, which consists of a LED, a hemispherical spirit level, and a photodiode array, to measure the shape of any 3-D object. This sensor uses the LED to project light on the bubble in the spirit level. The shadow is then projected onto the surface of the array composed of four equivalent p-n junction diodes, isolated by a cross on a wafer. By using a circular model for the shadow, the tilt angle and the direction in a two-dimensional plane can be obtained. However, this sensor is large (50mm x 50mm x 50mm) and accurate only when the tilt angle is less than 10 degrees. The error increases when the tilt angle increases because the shadow on the photodiode array is no longer circular, but elliptical.

Tanaka *et al.* [9] developed a portable instrument for long-term ambulatory monitoring of posture change using miniature electro-magnetic inclinometers. The size of the inclinometer is small (length=30mm, radius=13mm), and the dimensions of the computer unit are 33mm x 68mm x 110mm. The weight of the whole system is only 200g, and it is battery-powered. However, the angular resolution of this system is a coarse 12 degrees.

A posture monitoring system based on an accelerometer was developed to investigate whether this system can train people to improve posture.

2. MATERIALS AND METHODS

A low-power programmable data acquisition system was developed to monitor the angle of the back at around the 3rd or 4th thoracic vertebra position of the spine by using an accelerometer.

This system consists of an accelerometer, a low-powered 16-bit microcontroller, RAM, real time clock, a vibration motor and a battery pack. Figure 1 shows the block diagram of the system. The components inside the dotted lines are referred to as a digital data acquisition system. Figure 2 shows the approximate position of the accelerometer. The angle θ is close to 90 degrees when the subject is standing straight. The angle θ decreases when the subject bends forward.

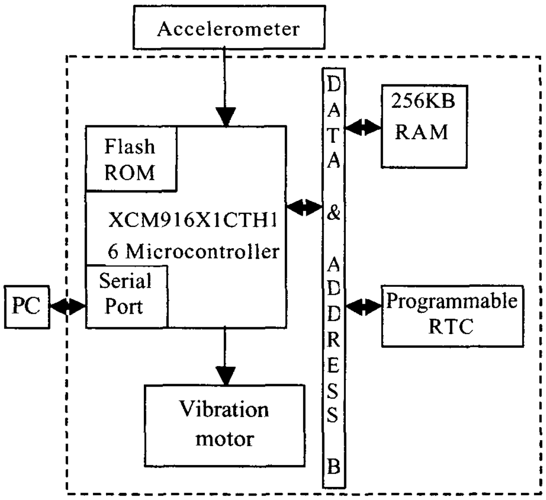


Figure 1. The Block diagram of the system

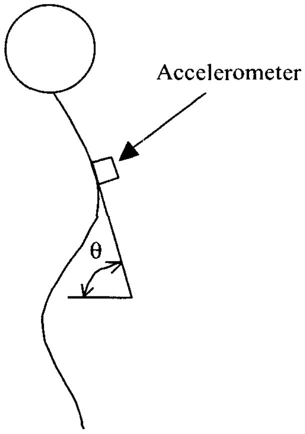


Figure. 2. The Free-body Diagram of the location of the accelerometer.

2.1. The Accelerometer

The accelerometer, ADXL202 from the Analog Devices Inc., with all the passive components was mounted on an area 2cm x 2cm x 0.5cm and its weight was 5 grams only (Figure 3). One axis measurement was used in this prototype. The output of the accelerometer is a digital signal whose duty cycle is proportional to the acceleration in the horizontal-axis. If the sensor is ideal, the duty cycle is 50% while θ is zero. However, due to the non-perfect device, calibration is recommended by the manufacturer.

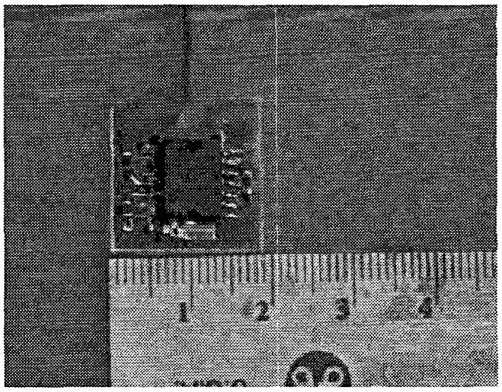


Figure 3. The accelerometer.

To do the calibration, the period of the accelerometer was set to 5.515 ms. The accelerometer was fixed at the end of a rotated arm which can rotate 360 degrees. The rotated angle can be read from the protractor on the rotated arm. Table 1 shows the calibration results of the duty cycle and the acceleration (g) from negative 90 to positive 90 degrees with 15 degree increments. Three measurements were recorded at each angle. When angle θ is zero, the value of g is 0.000; when angle θ is ± 90 degrees, the value of g is ± 1.000, respectively. In a perfect system, the duty cycle is changed from 37.5% to 62.5% while the angle is changed from –90 degrees to +90 degrees. However, in this accelerometer, the duty cycle is changed from 43.06% to 68.90%. The demonstrated sensitivity of this accelerometer is (68.9-43.06)/2 = 12.94%/g while the perfect device is 12.5%/g.

Table 1. Duty Cycle of the accelerometer

Angle (θ)	Duty Cycle (%)	Acceleration (g) (n=3)
-90	43.06	-1.000
-75	43.43	-0.972
-60	44.90	-0.858
-45	46.96	-0.698
-30	49.59	-0.494
-15	52.67	-0.256
0	55.98	0.000
15	59.26	0.254
30	62.38	0.495
45	65.00	0.698
60	67.27	0.874
75	68.36	0.958
90	68.90	1.000

The error of the angle measurement from the device is shown in table 2. The absolute maximum error is 1.6 degrees when comparing the angle measurement from a protractor as a reference. The error increases while the angle deviates from the zero degree increases.

Table 2. The error of the angle measurements from the device.

Angle (θ) (measured)	Angle (θ) (from device)	Absolute error
-90	-90.0	0.0
-75	-76.3	1.3
-60	-59.1	0.9
-45	-44.3	0.7
-30	-29.6	0.4
-15	-14.8	0.2
0	0.0	0.0
15	14.7	0.3
30	29.7	0.3
45	44.3	0.7
60	60.9	0.9
75	73.4	1.6
90	90.0	0.0

2.2. The digital data acquisition system

The dimensions of the data acquisition system (figure 4) were 6.5cm x12cm x2cm and its weight was 65 grams. The data acquisition system consisted of a 16-bit microcontroller XCM916X1CTH16 (Motorolar Inc.) with required circuitry, a real time clock, voltage regulator and 256K-Byte static RAM and a vibration motor. This microcontroller consumed very low power, had 48K flash memory for storing program data, and could be programmed to be in a low power STOP mode in which it consumed 100μA. The programmable real time clock (RTC) provided the sample time to the microcontroller. After the microcontroller calculated the measured angle, the data would be stored in the RAM. A feedback would be given if the measured angle was smaller than the threshold value. The microcontroller then reverts to STOP mode until the next interrupt. A low battery indicator was included in this system to alert patients to recharge the battery; a backup battery ensured the existing data remained in RAM. A nickel-metal hydride battery pack with 3.6 volt and 550mAh was chosen so that patient only needs to recharge the battery pack daily for 2 hours. The feedback is given by a vibrator, commonly used in pagers.

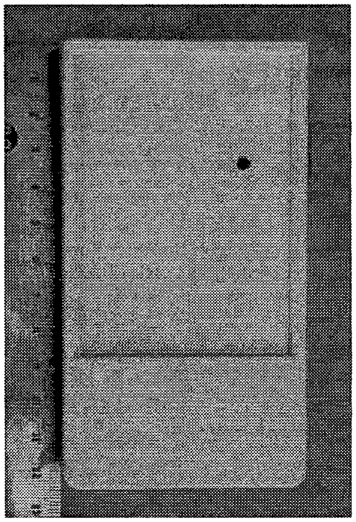


Figure 4. The digital data acquisition system.

3. PRELIMINARY CLINICAL TRIALS AND RESULTS

A subject who had kyphosis for many years volunteered to test the device. The subject was requested to do a series of activities in our laboratory before using it. The purpose of the activities was to determine the threshold value. The activities included normal standing (ST), bend to left (LB), bend to right (RB), forward bending (FB), backward bending (BB), sitting (SI), sitting with legs supported (SIS), writing (WR), standing while holding breath (SH), repeat normal standing (ST) and slouch (SL). Twenty samples at 0.5 seconds intervals were acquired at each posture. The average value was displayed. Figure 5 shows the angle measurements for the activities.

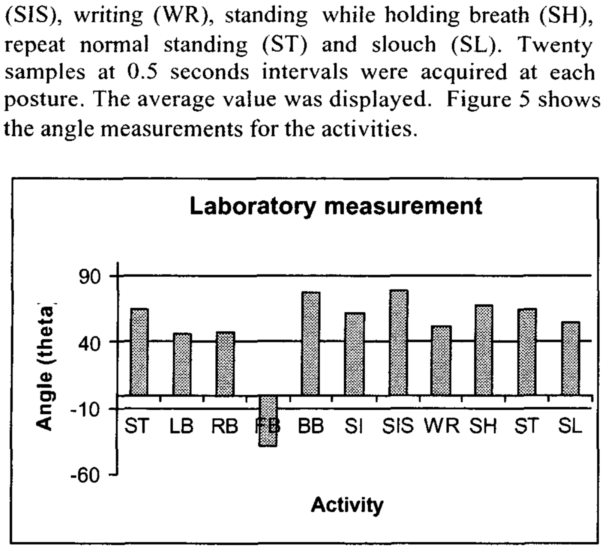


Figure 5. The angle measurement with different activities.

The threshold value was set to distinguish sloughing (SL) from appropriate standing. The subject then carried the device for two days. On the first day, there was no feedback provided. Feedback was provided the second day while the measured angle was less than the threshold value of 68 degrees. The 68 degrees was 5 degrees more than the normal standing. On the first day, the angle measurement was recorded during the subject's daily activities while he was in his office. The sample rate was one sample per minute. On the second day, the subject carries the system in two periods. The first one was from 8:00am to 12:30pm while he was working. The second period was from 9:pm to 11:00pm while he was relaxing and sitting at home. The sample rate was the same as the first day. Figure 6 shows the angle measurement from 11:00am to 5 pm on the first day. Figure 7 a and b show the angle measurements from 8:00 am to 12:20pm and from 9:10pm to 10:45pm on the second day, respectively. The average and the standard deviation of the angle measurement on the first day was 63±16 degrees. The average and standard deviation on the second day during day-time was 70±15 and during the night time was 74±12 degrees. The subject achieved a straighter posture when the feedback signal was turned on.

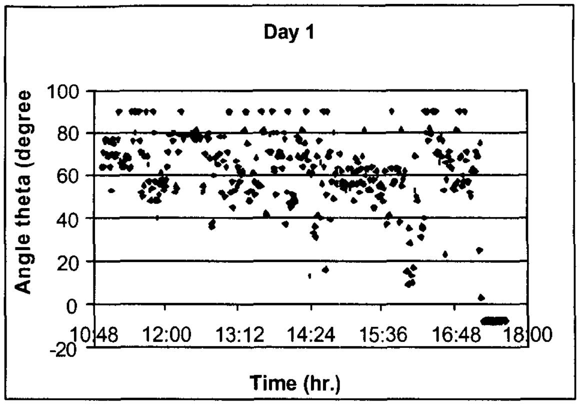
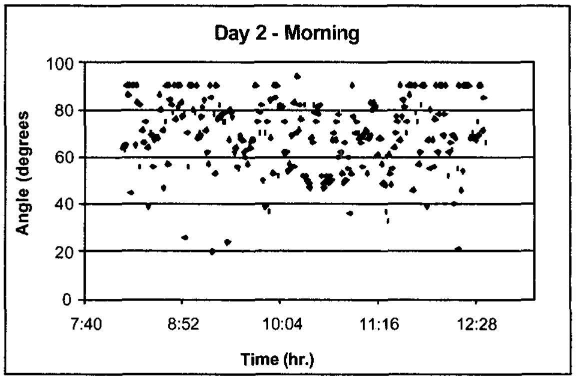
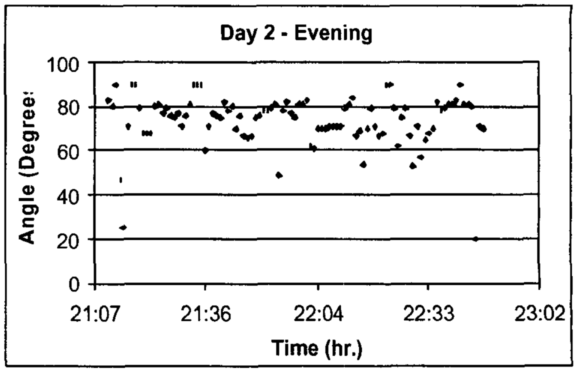


Figure 6. Day one results.



(a)



(b)

Figure 7a and b. Day 2 results.

4. CONCLUSIONS

A low-powered posture monitoring system for training people to improve posture which may reduce back pain has been developed. A subject tested the system for two days and reported that the device did not affect his normal activities. The results demonstrated that the device was able to detect the postural changes. This subject appeared to be able to positively affect his posture when feedback was given. Further clinical trials will be conducted before a definite conclusion can be reported on effect of learning an improved posture.

5. REFERENCES

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