Original Article

Design and Development of a 3-Axis Accelerometer Biofeedback System for Real-Time Correction of Neck Posture for Long-Time Computer Users

Abstract

Background: Due to long-term use of computers and not maintaining the correct position and angle of the body while working with it, various skeletal and muscular problems and pain in the neck area occurs. This study aims to use a biofeedbck system to alert the computer users of an inappropriate angle of their necks, and as a result help them to establish a correct neck position. **Method:** The user's neck angle is measured using a three dimensional accelerometer and the signal is processed, digitalized, and sent to the computer. User friendly software is designed to process the received data and warn the users when their neck angle is inappropriate. **Results:** The results show that the application of the biofeedback system reduces the users' total time with inappropriate neck angle to <50%. **Conclusion:** results demonstrated that training with the biofeedback system has been sufficient to make the habit of maintaining the neck in the correct angle.

Keywords: *Accelerometer, biofeedback, computer users*

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Introduction

There is no doubt that the advances in the technology have made different tasks much easier for people with various lifestyles. Nowadays, computer is one of the most revolutionary inventions of humankind, and it is intertwined with the daily activities of people in the way that it is difficult to pass a single day without using this device. Computers are involved in almost everything that human beings deal with in their daily activities. As a result, every person spends a significant portion of their time working with some sort of computers, including personal computers, laptops, etc. Despite their numerous advantages, long-time application of computers may also cause some physical and musculoskeletal issues. For instance, failure to maintain proper body posture and angle while working with computers for a long time can cause various musculoskeletal problems, pains, and disorders.[1-3] Neck pain due to the improper angle of the neck during prolonged work with a computer is one of the common musculoskeletal pains among computer users.[4-9]

Following the ergonomics guidelines regarding the proper position and angles of organs and joints my help computer users to reduce the neck pain. The main obstacle is that when computer users are concentrated on their work, they usually forget to maintain their proper posture. This issue may be addressed by utilizing the biofeedback techniques. The main task of a biofeedback system is to make the person aware of the parameters of his/her body that are either hidden to him/her or may forget to control them while they are concentrating on their work.

The biofeedback method has attracted the attention of many scientists and researchers in recent years because it can treat various problems and abnormalities without using any chemical medicine and suffering from their side effects.[10] Moreover, one of the top advantages of biofeedback method over treatment with medicine is that its effects remain even after the end of the treatment period. Therefore, after completing a

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period of biofeedback treatment, the recovered patient can continue his/her life without the biofeedback system and the abnormalities treated utilizing the biofeedback system will not recur in future.

The aim of this study is to use a bio-feedback system to alert the computer users of an incorrect angle of their neck, and consequently help them to establish a correct neck position.

In recent years, many researchers have been encouraged to use the biofeedback technique to treat a wide variety of disorders and valuable research and studies have been conducted in this field. Giggins *et al*. have categorized the biofeedback systems in a review paper and classified them into several categories, namely, neuromuscular biofeedback, electromyography biofeedback, heart rate (HR) biofeedback, real-time ultrasound imaging biofeedback, HR variability or respiratory sinus arrhythmia biofeedback, inertial sensors, force plate systems, electrogoniometery, pressure biofeedback unit, and camera-based systems.[11] Some other researchers have investigated the appropriate postures and angles for different organs and joints to use in biofeedback systems. In one study, Britt Larsson *et al*. have reviewed the studies on shoulder and neck pain, risks, methods of measurement, relevant medical images, and methods of prevention and treatment. In another work, two biofeedback systems have been used to help patients such as those suffering from Parkinson to maintain their balance. In these systems, accelerometer-based biofeedback has been used.[12-14] The biofeedback method for new-born and infant care systems was introduced in.[15]

Methods of sensing and extracting the neck angles have been presented by Bridget Armstrong and her colleagues.[16] In another study, Tadayon *et al*. introduce a mobile system to help people suffering from neck pain in every life circumstance.[17] Da-Yin Liao conducts another research on using accelerometer data to measure the neck angle and warn the user using light, sound, or vibration.[18] Zhang *et al*. and Riandy *et al*. introduce two wearable systems for body posture monitoring.[19,20] Although the functionality of these systems is satisfactory, wearing them disturbs the user and they are not designed specifically for computer users. In another study, in order to help to relieve neck pain in computer users, Breen *et al*. have designed a system to help these patients by neck angle measurement and warning the user using the visual and auditory alerts. In the visual warning, the color of a circle in the software is changed from green to red when the user's neck posture goes to an improper position and the auditory alert is a beep. They claimed that this system has helped computer users very effectively.[21] While the presented system demonstrated good performance, but it has some shortcomings. The first limitation is that a one-dimensional angle sensor was used. Therefore, the angle of the neck can be measured only in one direction. More importantly, the system is used to monitor the computer users only for 5 h, and not for a long time such as consecutive days. As a result, the habit of maintaining a proper neck angle is not developed in computer users. The aim of this work is to address these shortcomings and develop an improved neck biofeedback system for the computer users.

Methods

As stated in the introduction, this study seeks to help habitually adjustment of the neck angles utilizing biofeedback technique in computer users to reduce or prevent neck pain. In this research, we try to extract the angle and position of the user's neck using a three-dimensional accelerometer. These angles are transmitted to an Arduino processor board as three analog signals. The measured angles are then compared to the standard threshold angles extracted by ergonomics and rehabilitation specialists and warned the computer user if the neck angle is inappropriate.

Selecting these thresholds may depend on the several factors including the state of the user's disorder. Thus, the selection of appropriate thresholds for the neck posture should be conducted by a rehabilitation specialist. However, in order to prove the concept and validate the functionality of the system, in this study, ±20° is chosen as the threshold angles.

In order to evaluate the proposed biofeedback system, five computer users have been tested using this system at a given time. However, before that, in order to see the effectiveness of the proposed system to habituate the computer users to maintain a proper neck angle, the position and angle of the user's neck without biofeedback are recorded. Then, the user's neck angle is recorded and biofeedback is given to him/her when the neck is an adverse posture. After conducting the experiment with biofeedback for 7 days, another neck angle recording without biofeedback is conducted.

By comparing the results of these experiments, the effect of the designed system in helping computer users to keep their neck in a proper angle and as a result reducing the neck pain is assessed. More importantly, the influence of the proposed system on the establishment of the correct neck posture habit in the users can be assessed by comparing the recorded neck angles during pretraining and posttraining periods.

In short, in order to assess the effectiveness of the designed system, users first utilize the system without any biofeedback and duration of their incorrect postures is recorded. Then, for 7 days, users use the system with the help of biofeedback. At this step, users are warned to adjust their neck position when their neck is in a wrong angle. The durations of incorrect neck angles are recorded again. The efficiency of the system can be estimated by comparing the recorded time of inappropriate neck postures in steps one and two.

Finally, once again, the timing of user errors in maintaining his/her neck angle and posture are recorded without biofeedback to determine whether the system has been effective in establishing the correct neck posture habit.

Note that some errors in the measured angle might be observed due to the inclination of the headphone with respect to the normal vector to the ground. Therefore, every time the system is used it has to be calibrated. To this end, when the "connect" key is pressed and the initial neck angles of the user is shown in the combo box, the user must keep his/her neck straight and then adjust the headphone on his/her head in a way that 90° are shown in both the combo boxes of the graphical user interfaces. Alternatively, a calibration push button can be added to the software to correct the error due to the angle of the headphone with respect to the user's head.

Hardware design

For the hardware realization of the proposed biofeedback system, Arduino-Nano embedded system with ATMEL ATMega328 microcontroller is used. This board is very tiny (45 mm × 18 mm) and lightweight (5 g). Therefore, it is convenient to put on a headphone that the board is attached to it. Furthermore, this board has eight analog-to-digital conversion (ADC) terminals and a Universal Serial Bus connector making it appropriate for this project in which we need three ADC terminals and serial connection between the processor and computer. MMA7361 accelerometer module is used for the measurement of the angle θ between the neck and z-axis, which is the normal axis to the earth's surface. The MMA7361 accelerometer module is able to measure the angle between the earth's gravity vector and the X, Y, and Z axis on the surface of the module. The module then transmits the three measured angles to the embedded system as three analog signals. These analog signals are converted to digital values every 200 ms and transmitted to the computer by the Arduino board using an asynchronous serial protocol. User-friendly software (described in the next section) is designed to receive these digital values and perform the appropriate reaction (to warn the user about his/her improper neck angle) according to the calculated neck angle of the user. Photographs and schematic of the designed hardware are shown in Figures 1 and 2.

It is worth noting that, in some low-quality accelerometers, occasional errors are observed. This can be a serious issue, especially in applications in noisy environments or at high sampling rates. However, in the proposed application, environmental noise is not significant. Furthermore, since the neck movements are not very fast, only the five samples of accelerometer data per second are used. Therefore, the system is quite safe against the occasional errors in the accelerometer data and as a result, no preprocessing is required.

In case the proposed system is adversely affected by the application in noisy environments or when a high sampling rate is required, a simple averaging over accelerometer data can be used to remove rare errors in accelerometer data.

Software design

A screenshot of the software, which is designed using C# language, is shown in Figure 3. The software has a dropdown menu to select the computer port connected to the embedded system, connect and disconnect buttons to start or stop reading the transmitted X, Y, and Z angles from the accelerometer and some other options. Once the port is connected, the values for the front/back and left/right neck angles are displayed in the "Data" box. Different scenarios can be used to warn the user when his/her neck has an inappropriate angle. Two selectable modes are defined in the software. The first mode is "Daily Activities" mode in which the user performing their daily activities is warned for their inappropriate neck angle by reducing the monitor screen light, and returning the screen light back to normal when the user corrects their neck angle. The second mode in the software is "Music/Video" mode. By selecting this mode, the user can select and listen to or watch any desired video. When the neck angle exceeds the permissible limits, the music or video stops playing and alerts the user. Returning the neck angle to the allowed range will playback the music or video. It should be noted that in this software all WMV, WAV, MP3, and MP4 formats can be played. It is also envisaged to display full-screen videos for the convenience of the user. After pressing the "Disconnect" bottom, the software provides a complete report containing the date and time period of the experiment and the total number of improper neck angles in x-axis and y-axis, as well as the user-selected mode (daily activity-music/video).

Results and Discussion

In order to validate the method and the designed hardware and software and to assess its effect on the users, the designed system was tested on eight users. Each person has used the biofeedback system for 33 min/day for 10 days. On the 1st day, the system gives no biofeedback to the users and it just records the user's neck angle. Starting from the 2nd day, the system gives the biofeedback to the users. Figure 4 compares the 1st and 2nd days in terms of the total time that each user's neck has been in an improper posture. The figure clearly shows the significant influence of the biofeedback system on reducing the time that the user's neck angle has been in improper angle.

The experiment with biofeedback has been conducted for seven more days. Figure 5 shows that in all cases the total time in which the user's neck is in an improper posture reduces after the 8 days use of the biofeedback training system.

As mentioned earlier, one of the main advantages of the proposed system is its ability to habituate the users to maintain

Figure 1: Designed hardware and system appearance mounted on a headphone

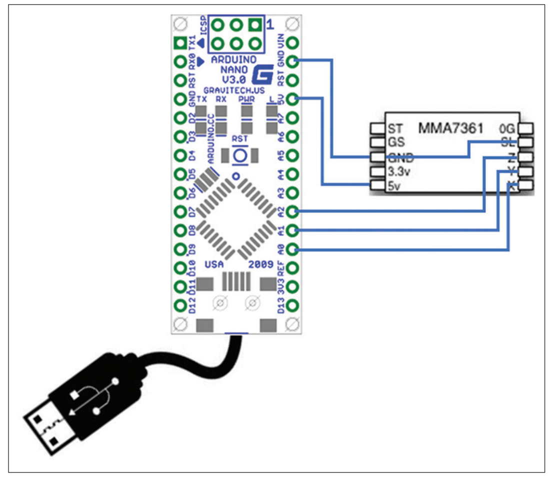

Figure 2: The schematic of the designed hardware

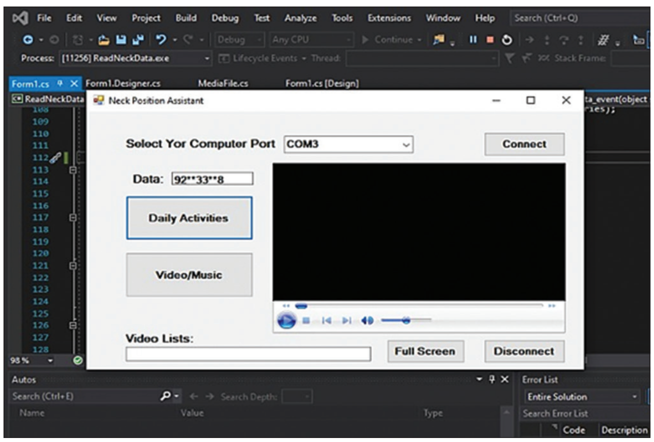

Figure 3: The appearance of designed software

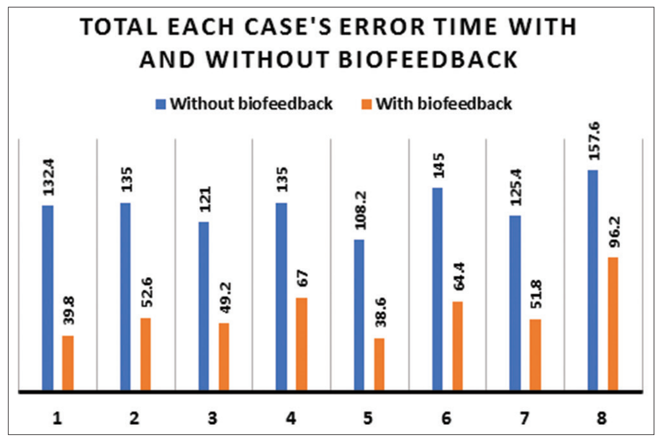

Figure 4: A comparison between first (without giving biofeedback to user) and second (giving biofeedback to user) days

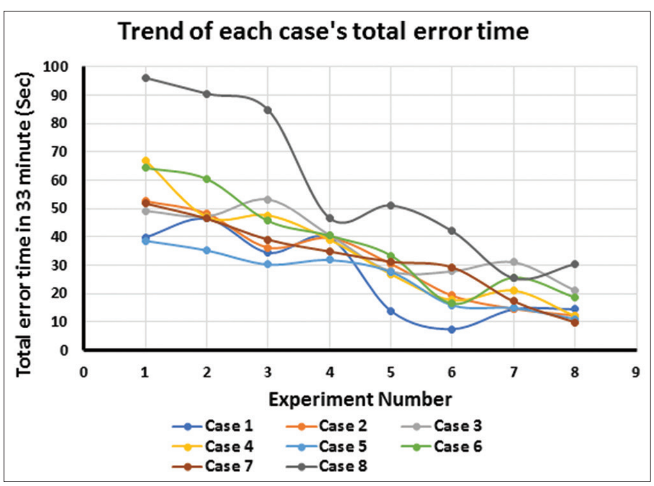

Figure 5: The total time in which the user's neck is in an improper posture versus experiment number

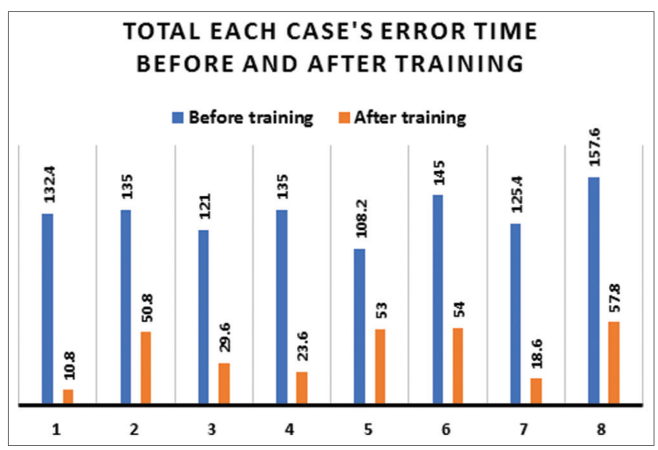

Figure 6: A comparison between first and final days (without biofeedback)

their necks in a proper angle even without biofeedback. To validate this potential, after the 9 days of training with biofeedback, another 1-day experiment without giving biofeedback to the users is conducted (an experiment same as the one conducted on the 1st day). A comparison between the results of the first and the last day of experiments, i.e., the days without biofeedback, is depicted in Figure 6. The figure shows that the total time of improper neck angle on the last day is much less than that of the 1st day.

Conclusions

This study has attempted to use a biofeedback system to alert the computer users when they put their necks in an inappropriate angle. The system extracts the users' neck angle in two directions using a three-dimensional accelerometer. These angles are transmitted to a microcontroller to be compared to the correct positioning angle thresholds extracted by rehabilitation specialists. The system gives an alert to the users when their neck angle is inappropriate. The results have shown that: First, using the biofeedback system may reduce the time of improper neck angle to 50%. Second, the application of the biofeedback system for a longer time (up to 8 days in this study) results in an obvious reduction trend in the users' improper neck posture. Finally, after 8 days of training with the biofeedback system, the establishment of the habit of positioning the neck within the healthy angle limits is clear. In fact, after 8 days of training with the biofeedback system, the total time of the improper neck posture without biofeedback has been dramatically decreased.

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Conflicts of interest

There are no conflicts of interest.

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