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Research Article

Wearable sensor device for posture monitoring and analysis during daily activities: A preliminary study

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ABSTRACT

The increase in technological advancements in recent years has led to the emergence of a new lifestyle. Although being assisted by machines for small-scale tasks in daily housework makes daily life easier, this has caused people to reduce their daily active movements and negatively affects human health. Especially during the COVID-19 pandemic, with the conversion of the working style to the home environment, working hours spent at the desk are more than ever. Due to the prolongation of the working time, the employees stay in the same position more inactive, thus their muscles weaken and they start to have muscle disease. Weaknesses in the muscles have occurred to the formation of postural problems in people. In our study, a smart vest system was developed to detect and control posture disorders. The proposed system is designed to recommend the most suitable exercises to avoid any physical discomforts. It is also aimed to detect hunched posture by collecting data on the person wearing the vest through sensors. Besides, it is encouraged to correct the posture disorder by warning the person audibly during the hunched posture. The experiments conducted with eight participants showed that the proposed system warns the users with necessary posture corrections, proving its potential use.

1. Introduction

The rapid acceleration of technological developments has made our lives easier in many ways, and besides, physical labor has left its place to machine-based work. In the present age machines are used in many professions because of cheap labor costs so that, working activities of people are decreasing day by day [1]. It is seen that the inadequacy of the inspection processes regarding the compliance of the working conditions in the workplaces with the ergonomics rules seriously puts the health of the people at risk. Recently epidemics caused changes in working conditions and forms. With the appearance of COVID-19, most companies demanded their employees to work at the home office and bring flexible office working. In this way, employees have come to a position to work more than before at their current working hours [2]. Even if they have an ergonomic chair at the office, they couldn't find the same environment at home thus physical activities were decreased. Due the increase in the time spent at the computer than usual, the inactivity of the muscles in the waist and neck region increases and weakens and causes posture disorders.

Posture disorder, which is a muscle problem [3], can be encountered in every stage of our life such as growth, aging, working or sports periods. Early interventions to these deformations have been proven to significantly strengthen the healing processes. The factor of recovery in childhood is much stronger than at an earlier stage in life. With today's advancing technology, wearable posture monitoring devices assist in the treatment of these spinal deformities [4-6]. Pandian and Mohanavelu [7] stated that conventional sensors and medical devices are known to be quite difficult to wear for long periods of time as wearables are unusable for physiological monitoring applications. There was a need for better quality monitoring and physiological support in the market. In line with our study, primarily employees and children were targeted. In this context, a smart vest was designed that people can wear comfortably while performing physiotherapeutic movements suitable for their age category. Along with the proposed system, it is also aimed to develop and analyze a smart vest for posture tracking in physiotherapy rehabilitation exercises. People often have to pay a lot of money to be able to do physiotherapeutic exercises and

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cannot go to rehabilitation centers on a regular basis. For this reason, home rehabilitation has various benefits in terms of both the extended effectiveness of health care and relaxation for the patient [8-10]. With the smart vest, people will be able to do their exercises comfortably at home. Reduction of behavioral disorders due to the utilization of smart vest will be a natural result.

In this study, we developed a sensor-based assistive device that not only warns the individual, but also aids to maintain the ideal posture. In order to examine the effectiveness of the smart vest on posture disorder, we tested it during activities such as walking, sitting and running. With this study, it is aimed that individuals with postural disorders can rehabilitate this problem with the help of a wearable system without affecting their daily lives. The major objectives of this study are:

- Developing a low-cost wearable sensor device to monitor posture during daily activities,
- Real-time transmission of posture data via the microcontroller's Bluetooth interface to increase system availability and analyze data simultaneously.
- To gain the habit of correct posture, in the long run, suggest daily exercises based on the postural structure of individuals through a mobile app.

The rest of this paper is organized as follows: Section 2 surveys the related work in the literature, Section 3 explores the proposed system. We present results on the preliminary experiments in Section 4, and conclude in Section 5.

2. Literature Research

The simplest definition of the concept of posture in the medical language can be defined to be the correct standing of the skeletal system [11]. Many factors affect the posture of the body, some of which are; body type, physical habits, genetic structure and muscle balance. Familial factors, structural disorders and habits are determinants of posture in humans. Posture disorders are usually caused by the weakening of the muscles due to improper sitting for a long time. It is necessary to be very carefully perform sports or various activities; otherwise, health problems may occur [12]. The body acquires a proper posture as a result of the harmonious operation of many muscles with the help of its ligaments during movement. While the skeleton is in a normal state, there is a partial hump on the back [13] as shown on Figure 1. Many of existing posture monitoring systems studies include sensor technology. Numerous useful results have been obtained with the employment of sensors and developing technology on products that people use daily. As a result of the rapid development on wearables, studies that establish a direct connection between the human body and smart devices have become widespread [14, 15].

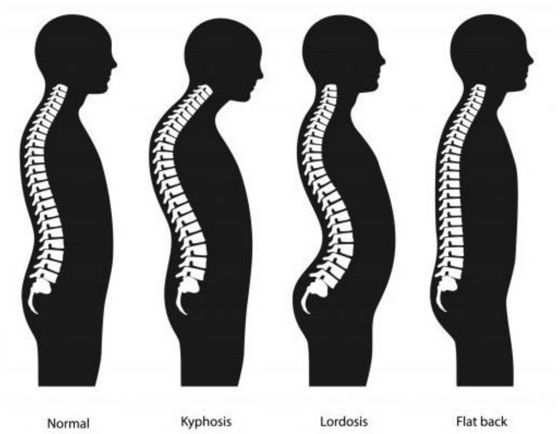

Figure 1. Lateral view of posture positions: the first image is normal or straight posture, the second one displays kyphosis is spine dysfunction, the third image lordosis is the reverse of a hunchback, and in the last one, the spine becomes flat because it loses its natural lower back curve

The fact that such devices communicate with each other and create interfaces on mobile devices using various protocols and wireless technologies such as Bluetooth has made the use of devices popular. Many wearable technology devices and applications have been developed especially for use in the health domain [16, 17]. The most well-known feature of these devices with health applications is that they can measure and monitor motor activities along with various physiological data such as heart rate, amount of oxygen in the blood, body temperature. As a result of long-term desk work neck flattening and back pain are increasing day by day. In particular, health problems occur as a result of many faulty situations such as not using smart devices, increasing erroneous sitting times, falling asleep at the desk [18-21]. As a consequence of these reasons, the technological interest in wearable devices for the prevention of back and low back pain in terms of health applications in the developing market is increasing [22, 23].

Due to the COVID-19 disease, which has affected the whole world in the last two years, it has caused many changes in people's social and business lives. A new lifestyle has been developed at home due to pandemic. With this new lifestyle, institutions have introduced a new working model called working from home by adopting remote working models for people who are in working life. The time spent at the desk increased, while the time spent at the desk increased in relation to this sudden change due to improper implementation of this new approach [24]. The increase in the time spent at the desk has led to the emergence of some symptoms in individuals of all age groups. It has been ensured that chairs, clothes, and wearable devices can be integrated into many different platforms with the positive progress of sensor technology [25-27].

The main motivation of our study is to contribute to improving the quality of life of individuals with postural disorders by performing bodily characteristic analyzes with correct information and evaluating these data with correct techniques. Health-conscious people think that they need to "fix" their posture and, to a large extent, neck pain, headaches, and especially lower back pain [28]. Precise posture is vital for balance. Correct posture plays a vital role not only in daily life but also in professional life. For example, playing in balance in any sport will strengthen one's abilities in the activity and even increase the duration of the activity. Physical causes of poor posture may include some medical history [29]. In these cases, expert care and diagnosis are necessary to correct negative posture [30].

3. Method

3.1 Wearable Device Design

In our proposed study, the vest's task is to detect and analyze postural imbalance instead of eliminating posture disorder like other vests introduced in the literature. In this context, measurements were collected from sensors placed on different parts of the body. The vest has an adjustable design with back pockets, for ensuring accurate sensor location and measurement. Since it has elastic fabric, people of different body sizes can wear it easily; this is an important factor for the accurate positioning of the sensors during spinal movements and can also be crucial to support long-term usage. In addition, its adhesion to the skin allows us to make a healthier data measurement. Points A, B, C, D, E on the back of the prototype vest shown in Figure 2 below are designated as sensor placement points. A and B are alternative sensor placement locations to be used in measurements to be made from the dorsal region. Likewise, the D and E pockets are designed to be used in choosing the most suitable place on the waist. Zone C pocket is designed to increase the development efficiency of the work. With this pocket, optional sensors such as pulse, temperature, etc. can be placed, and data measurements can be collected, accordingly.

The system consists of a central microcontroller embedded with a number sensors to monitor and analyze users' posture during daily activities. As the central component Arduino UNO R3 processor equipped microcontroller is used to orchestrate the sensor platform. The system is equipped with HC05 Bluetooth module to connect mobile app. In addition, two MPU6050 that have both a 3-axis accelerometer and 3-axis gyroscope integrated on a single chip were employed to monitor and analyze posture. MPU6050 uses I2C communication protocol that enables efficient retrieval of data from both sensors by activating the AD0 addressing pin. This allows measuring rotational velocity or rate of change of the angular position over time, along the X, Y, and Z-axis. The sensors are calibrated to send feedback through the gateway when unequal pressures are sensed between them.

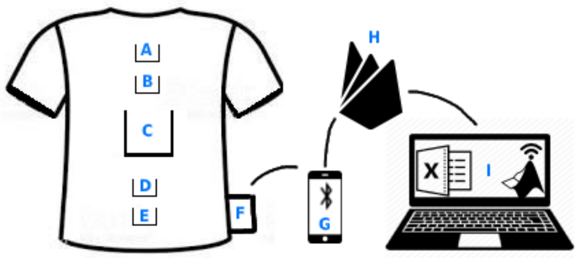

Figure 2. View of the proposed wearable vest and data flow: A, B, C, D, E on the back of the prototype vest shown are designated as sensor placement points

Figure 3. First prototype of posture monitoring vest with multiple pockets on the back to place accelerometer sensors.

Therefore, if the pressure applied to the sensors placed on the back is higher than the set threshold value and as a result, a light on the vest lights up and gives an audible warning with vibrotactile feedback is generated to alert the user. The proposed prototype is powered by a lithium-ion battery and can perform an average of 7 hours of continuous data transfer.

Figure 2 also shows the prototype and data flow lifecycle. Vest data, which is a data fusion from multiple sensors, is processed through sensor platform and becomes usable in real-time. After preprocessing raw data, it is transferred to the Firebase Realtime Database and remains available when application goes offline. We used Firebase to easily access and analyze the stored data. We have conducted a number of experiments to make sure that all services are operational and data transfer are lossless. Figure 3 shows two participants wearing the proposed posture monitoring vest prototype.

Measurements from the back are compared between the two sensors after data preprocessing. As a result of this comparison, the posture disorder tray of the user varies according to the points where the sensors are attached. The sensors used in the system were placed on the back and waist region to determine the hump status. Referencing to the degree of humpback, which is angularly graded, the user is prompted with an audible warning by means of a bell, allowing her/him to correct his posture.

3.2 Mobile Application Design

A mobile application was developed to transfer the collected data and show it to the end user. Android Studio was preferred as the development interface and Android 11 SDK (API level 30) was used to develop the application. The data collected during the day and during the activity is stored in the Firebase database and reported via the mobile app. Android app uses Bluetooth connection, to discover, connect and communicate with the vest. Figure 4 shows the interfaces of the application.

We aimed for the application to use data according to different activities such as walking, sitting, running etc. to be performed at different times of the day. The system also keeps demographic information of the user such as age, height, weight, and gender.

We have developed interfaces (Figure 5) to control user's movements and provide postural balance. If the user wants to learn the postural balance in the sitting position, by clicking the *Good Sitting* button, she/he can obtain many information such as the appropriate page position, the angular balance of the body and the upright state, both verbally and visually [31]. Other tabs show the right and wrong directions of the walking and running pole. It also includes verbal narration and provides a clear physical therapy support through visual explanations. The accelerometer on the smart vest transmits the information of linear changes in three planes. In this way, both the curvatures of the back and the movement of the body are detected. In order to determine the posture disorder, the measured data are compared with the threshold values that we define as correct posture. Following that, the slopes in the back area can be determined and posture suggestion is made.

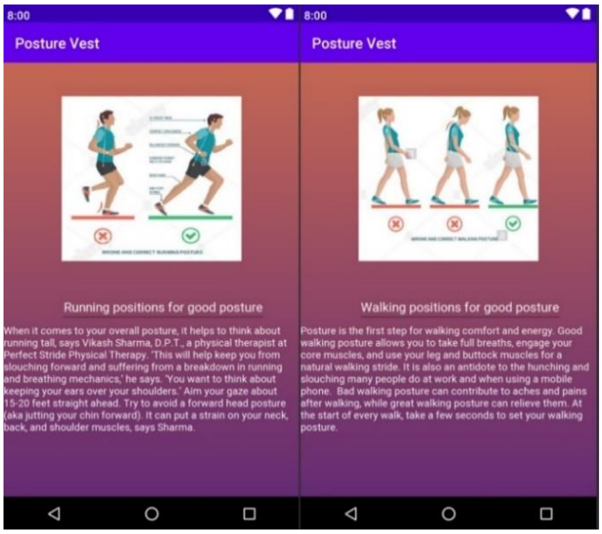

Figure 4. Sample view from the mobile application that includes right and wrong directions of the walking and running activities

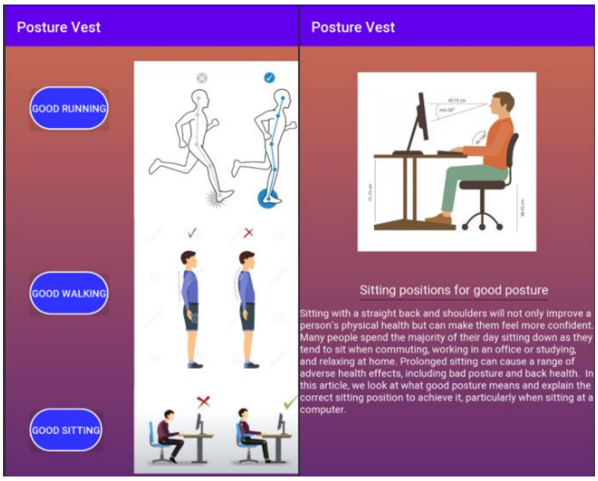

Figure 5. Correct posture suggestions and explanations for different activities

4. Experimental Results

While most of the wearable devices in the literature promise potential use in a broad variety of clinical applications, the most prominent challenge is the lack of validation of these sensors. For this reason, the studies first go through the stages of prototype designs and testing, so that the devices are pre-verified. We also conducted a preliminary study to validate the use of the prototype we developed as part of the study for long-term postural monitoring and improvement. Larger and longer-term validation studies are needed following the study.

Traditionally, several tests are performed in hospitals for preliminary diagnosis for patients with postural disorders. During pandemic, the hospital environment is thought to be dangerous for patients [32]. By using smart wearable vests, it is determined which tests should be done to patients in hospitals. The data of the movements of the participants were displayed and analyzed through the developed mobile application. Recommended analyzes consist of three different activities such as sitting, running and walking tests. The experiments were performed by eight subjects, five females and three males aged between 18 and 51.

Three of the females and one male were the scoliosis patient; the remaining participants did not declare any back condition or any other treatment. A total of 720 minutes of data were obtained by recording 30 minutes of each activity. We gathered 216000 data points from each sensor with a 5Hz sample rate. In order to determine the sitting positions; head control, trunk control, and foot control were performed. In the sitting tests, we observed that 70% of the participants take the warning system as a basis and change their posture within 5 seconds. When we evaluated the posture of the people during walking with the walking test, we found that the reaction times of the participants decreased by 3 to 5 seconds compared to sitting position. The data we measured from the participants at 12ms intervals showed deterioration in signal during walking and more noisy data than sitting activity. Running test results also have noisy data comparable to walking results. However, we observed 30% less hunched posture during walking and running (Figure 6).

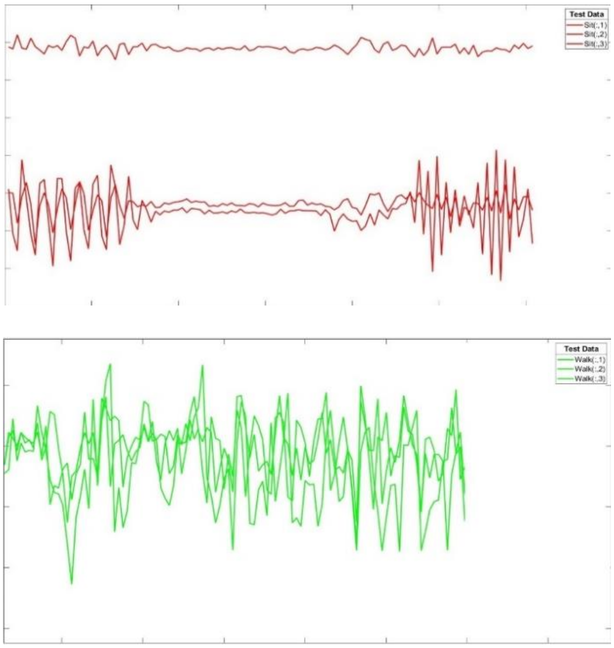

Figure 6. Sample sensor data from sitting and walking activities

Because of COVID-19 pandemic and its limitations, the experiment analyze phase is conducted with limited number of users. Besides, personal information such as height, weight, age and gender of the users were not taken into account. As this study will continue, demographic information will be taken into account in the second version of the vest. With initial prototype, we aimed to develop services that will rehabilitate scoliosis with audible stimuli. In case of regular use, the main goal is to make the user a habit of correct posture.

5. Conclusions

The gradual increase in epidemics such as Covid-19, shows us that people are less likely to reach doctors and health institutions during lockdowns. In addition, there is an inverse correlation between the increasing number of patients in hospitals and the number of health workers. Healthcare professionals can allocate less time to other patients, as they give priority to patients affected by the viruses during epidemic periods. For this reason, the treatment period of the patients is postponed to a later date and the recovery period of the patients may be extended. Today, the hospital-centered treatment approach is being replaced by the patient-centered approach. With the mobile health monitoring systems developed today, it has become possible for patients to continue their treatment at home without the need to go to a hospital or health institution. Our study offers a national alternative to research on posture disorders. With the proposed system, sensor readings of people with posture disorders are recorded and analyzed using low-cost stock sensors to support traditional rehabilitation. In this study, the wearable vest system designed has been implemented using wireless network technologies to strengthen interaction with mobile systems. As the continuation of this work, we will focus on improvements for the ergonomics of the smart vest and make it suitable for daily use.

Declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors also declared that this article is original, was prepared in accordance with international publication and research ethics. All procedures and protocols were approved by the ethical committee at Istanbul Kultur University (approval number: 2020.29).

Author Contributions

G. Özgül developed the methodology, performed the analysis and F. Patlar Akbulut supervised and improved the study.

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