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Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE).

Design of a Wearable Smart Device for Sitting Posture-Monitoring System.

By:

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A Dissertation Submitted to the Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE), University of Rwanda as partial fulfillment of the requirements for the master's degree in biomedical engineering.

Supervised by Prof. Damien HANYURWIMFURA and Prof. David K. TUMUSIIME

DECLARATION

I, Nadine UWINEZA, declare that this dissertation entitled "Design of a wearable device for smart posture monitoring system" is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

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Student Signature: ____________________________

Date: ______________________________

CERTIFICATE

This is to certify that the project entitled "Design of a wearable device for smart posture monitoring system" is a record of original work done by Nadine UWINEZA. (222000301) an MSc. Degree student in Biomedical Engineering.

This work has been submitted under the guidance of Prof. David K Tumusiime and Damien HANYURWIMFURA

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ABSTRACT

The wearable smart device designed for monitoring sitting posture offers an innovative solution to detect spinal deviations like scoliosis and kyphosis. Utilizing a flexor sensor, the device accurately captures data on the user's posture, which is then transmitted to the cloud platform Thingspeak for real-time monitoring. This enables users to receive immediate feedback on their sitting position, helping them to maintain a correct posture and potentially mitigate spinal issues. In the event of incorrect posture, the device provides notifications through buzzer, vibration, or LED indicators, prompting users to adjust their position accordingly.

One of the key features of the device is its cost-effectiveness and portability, making it suitable for use in various settings. This accessibility ensures that individuals can benefit from posture monitoring regardless of their location. However, to improve accuracy, future iterations of the device are recommended to incorporate a longer flexor sensor, addressing the specific measurement requirement of 4.3 cm. This enhancement would likely enhance the device's ability to detect and track spinal deviations more precisely, thereby further enhancing its effectiveness in promoting healthy sitting habits and preventing spinal issues.

Overall, the wearable smart device represents a promising tool for promoting spinal health by providing real-time posture monitoring and feedback. Its affordability and portability make it accessible to a wide range of users, with the potential to have a positive impact on individuals' spinal health and overall well-being.

Keywords: Flexor sensor, Buzzer, Vibrator, LED, Scoliosis, and kyphosis.

LIST OF ACRONYMS

API: Application Programming Interface

DB: decibel

Hz: Hertz

I/O: Input and output

IoT: Internet of Things

Mcu: Microcontroller Unit

MSD: Musculoskeletal Disorders

WI-FI: Wireless Fidelity

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CHAPTER 1. GENERAL INTRODUCTION

1.1.Introduction

Nowadays there is a rise in musculoskeletal disorders (MSDs) due to the prolonged sitting in bad sitting position mainly in the office, the previous research confirm that the bad sitting position affect the spine [1], which result to be attacked by scoliosis, lordosis, kyphosis and chronic low back pain [2]. This issue will continue to affect a large number of populations in the world because of many daily working hours while they are in poor sitting position.

According to research about Low-back pain, the annual prevalence of chronic low back pain in the population ranges from 15% to 45%, with a point prevalence of 30% [3] and one of the causes of lower back pain is to sit for a long time in a bad sitting position. In addition, this is a worldwide problem due to the cost of treating the effect of low back pain because of poor sitting position. It is reported that this issue affects the socioeconomic of different countries, in the United States in 2006 exceeded US$100 billion, whereas in the Netherlands the total cost of low back pain in 2007 was estimated at €3.5 billion [4].

In Rwanda poor sitting position affects the large number of office workers according to research conducted on the workers in the bank among the 144-bank staff who were asked and the 45.8 % experience low back pain [5]. The study concludes that there is a high prevalence of back pain among bank staff and factors like back bent, back twisted, and having no break off during working time are independently associated with back pain among bank offices. The lower back pain does not affect-only bank staff in Rwanda but also the nurses, about 54.4% are affected [6]. The poor sitting position also affects the students at high schools and university according to the research by Paul Ndahimana carried out in Nyamasheke district. The low back pain prevalence was found to be 66.1% among the selected sample [7]. Based on that research the poor sitting position/posture is the serious problem that hinders the health and socioeconomic activities.

Design Smart Sitting Posture Monitoring System that accurately detects and monitors posture, provides timely feedback, promotes healthy habits to prevent musculoskeletal disorders. Design Smart Sitting Posture Monitoring System is made of the flexor sensor that detects the bending of the spine and the NodeMcu which processes the data and transmits the data to the database that stores all information of the sitting position of the users. Therefore, an alert in the form of light, Vibrator and sound is given to the users by Led, vibrator and buzzer, the users select the alerting system on his/her wishes. The smart sitting posture monitoring system is mainly based on detecting the poor sitting positions when the user sits in a position rather than the normal spine curve, scoliosis, and hyper-kyphosis posture because it is the main bad sitting posture many workers use to sit.

1.2.Problem Statement

The prevalence of musculoskeletal disorders due to poor posture and inadequate ergonomic practice is a growing concern. Existing methods for sitting posture-monitoring systems are limited due to their applications, where sensors are embedded in chairs and causing the system to be costly, highly complicated and not usable everywhere. Furthermore, such high technology cannot be accessible to low-income people. Therefore, there is a need for a robust Smart Posture Monitoring System that accurately detects and monitors posture, provides timely feedback, and promotes healthy habits to prevent musculoskeletal disorders.

1.3.Research Objectives

1.3.1. General objective

To design and prototyping a smart sitting posture monitoring system for preventing musculoskeletal disorders.

1.3.2. Specific objectives

- **I.** Review the existing sitting posture methods for their weakness and limitations.
- II. To design wearable devices integrated with sensors that are comfortable designed to be worn on the body, specifically targeting the user’s back region.
- III. Prototyping the wearable device to ensure its accuracy in detecting and notifying the user of poor posture.
- IV. Testing and evaluating the proposed device for performance with the existing device systems.

1.4. Study Scope

This research focuses on the people sitting in kyphosis and scoliosis positions and is targeting only office workers.

1.5.Significance of study

Developing a wearable device that can effectively detect in real time poor sitting posture has many advantages for the users.

- **Health and Wellness Improvement:** Poor posture is a common cause of musculoskeletal problems, including back pain, neck pain, and headaches. A smart posture monitoring system can help users become more aware of their posture habits and make adjustments to prevent health issues.
- **Prevention of Musculoskeletal Disorders:** By providing real-time feedback, the system can help prevent the development of musculoskeletal disorders related to poor posture. Early intervention can mitigate the risk of chronic conditions and improve overall well-being.
- **Increased Productivity:** Maintaining good posture is linked to improved concentration and productivity. A system that notifies users of poor posture encourages them to maintain a healthier posture, potentially enhancing their focus and work efficiency.
- **Education and Awareness:** The system can serve as an educational tool, raising awareness about the importance of proper posture. Users can gain insights into their posture habits and learn how to make positive changes, leading to long-term posture improvement.

CHAPTER 2. LITERATURE REVIEW

Poor sitting posture influences the health of the individual and the social economy of the individuals and the country in general. To prevent the effect caused by the poor sitting posture there are many assistive devices used for good ergonomics when sitting, they are passive devices like comfortable chairs and active devices like chairs, wearable devices that have the sensing and alerting system for poor sitting positions. They are different pieces of work related to poor sitting posture monitoring, this section summarizes the workers related to designing, prototyping and implementing the poor posture monitoring system.

A.R Anwary [2] introduced design of A Real Time Sitting Posture Monitoring System, the idea was developed due the "Prolonged asymmetrical sitting which is common and can exacerbate musculoskeletal back pain and spinal deformities" and they decide to design a device for monitoring sitting posture can help maintain correct posture and prevent health problems. The device is made of a Sitting Pressure Sensor that senses the applied user's pressure on the chair by using the internet of things data that is transferred to the cloud. The A rule-based classifier is used to provide timely notification to users about sitting duration and level of asymmetry.in their design the siting pressure sensor were used, to measure the pressure on shoulder, back thigh and front thigh, at each region two pressure sensors are used on those parts [2].

In their experiment carried on 10 healthy people, they were asked to sit different position to determine the range of pressure in normal sitting position and asymmetrical positions (poor asymmetrical position) and it was discovered that percentage of sitting pressure in shoulder areas is 80%, back thigh areas are around 79% and front thigh areas is around 82% for normal sitting from all subjects while to determine the asymmetrical position the difference in pressure at two sensors located at the same part is recorded. The asymmetrical position is mild, moderate and severe and are classified according to difference in pressure. Mild asymmetry Boxplots show that percentage range is from 0 to 40 and more than 75% data lie between 0 to 20. Moderate asymmetry the percentage range is from 20 to less than 80 and more than 75% data lie between 20 to 55. The percentage range is from 20 to 100 (shoulder), 60 to 100 (lower back) and 65 to 100 (thigh) for severe asymmetry [2]. The developed sitting posture monitoring system called Smart-Cover is limited to its application where a chair seat cover is embedded with SPSs, therefore my contribution will be to design a wearable device that is comfortable designed to be worn on the body, in a different chair specifically targeting the user's back area. This developed device has high accuracy but is challenging to the users in case they need to move to another office and it is expensive and cannot be afforded by everyone and to get the alert only is applicable to smartphone users.

Another work by Xu Ran, Cong Wang proposed a portable sitting posture monitoring system to recognize the user's sitting posture and feedback the results in real time [8]. A pressure sensor array is used to collect sitting posture related information, while the collected data can be displayed on a computer. The proposed system was designed to recognize seven types of sitting postures, including sitting upright, leaning forward, leaning backward, leaning left, leaning right, cross left leg, and cross right leg.

The hardware was controlled by Seven machine learning algorithms and through them the five-layer Artificial Neural Network is the one that achieve the highest accuracy of 97.07 %. To achieve the design the pressure sensors based sitting posture monitoring systems are implemented by installing pressure sensors on chair surface and back.in their work the high-resolution sensor array was a key component. Each sensor generates a voltage the pressure is applied, then that voltage is acquired by a data acquisition card that collects it and performs ADC, and after transmits the sitting posture related data to the Raspberry Pi via Universal Serial Bus (USB). Therefore, the Raspberry Pi with a series of machine learning algorithm data process sitting posture data and displayed on the computer. For maintaining the user’s posture if the measured pressure is not the recommended one the vibration alert is done. This technology is good for poor posture monitoring and has high accuracy, but the problem is also the system is inserted in chairs and their alerting system is limited to vibration and this can cause other health problems due to the vibration energy(waves).

Another piece of work by Jongryun Roh designed the Sitting Posture Monitoring System Based on a Low-Cost Load Cell Using Machine Learning. It is designed to replace the existing sitting frame of the office chair with a new one that has a monitoring system. The load-cell are inserted at each end to measure the applied mass [9]

The seat frame had four low-cost load cells and the location of each load cell was marked as the left and right sides of the thigh position, as well as the left and right sides of the buttock position. All the load cells were placed at a 70 mm distance from each corner of the seat plate. The real-time data on the load (kg) measured on the four load cells were transferred to a personal computer (PC) via the Arduino board. To test the device 24 healthy adult males (age: 27.6 ± 5.6 years, height: 174.5 ± 6.2 cm, and body weight: 71.9 ± 8.7 kg). The selected subjects regularly worked with a video display terminal, sitting on office chairs for eight or more hours a day, and had no apparent severe musculoskeletal deformity or nervous system abnormality. They were requested to sit in different positions shown in figure 2.4.

After collecting and analyzing the data it was approved that sitting in first position (regarding the above image) is the best sitting position because the mass is distributed equally at all points. The device uses the load cell, which needs calibration after some time, and this makes the device have low accuracy when calibration is not done on time. Researchers addressed the future work that needs to be done, which is also my interest by designing a wearable posture monitoring system that is comfortable, easy to use and efficient in terms of the posture accuracy, the time-system treatment and feedback [9].

Another piece of work is wearable Posture Identification System for Good Sitting Position [10], they designed the wearable device for monitoring good sitting position by using the accelerometer. The first accelerometer was placed on the human lumbar spine while the second accelerometer was placed on the human cervical spine.

A wearable device for monitoring good position by using an accelerometer. Good posture is defined as ears aligned with the shoulder's blades; the posture of the head, especially the neck, should be constantly the 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 cause neck pain, the accelerometer was used to record angle between the trunk and neck when the user changes the position. In their experiment, three students were asked to change positions and the angle was recorded. It was concluded that the system is good for portable and wearable posture identification systems for good sitting position and is developed for monitoring and warning on students' sitting posture. However, the new system can work 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 [10]. In this work the detection system is designed and developed but the alerting system is not yet developed which makes it to be unsuitable used for timely monitoring the poor sitting positions.

Android-based low-cost sitting posture monitoring system was designed, the flex sensor is inserted in wearable devices to detect deflection, and the Bluetooth module was used to transfer the data to the designed mobile app [11]. The notifications are displayed according to the threshold value. A flexor sensor is inserted in the sensing belt and Arduino Nano is used to read the sensor value and then convert an angle. The notification is sent through a Bluetooth module to mobile applications. The device was tested and gave good results, in addition is cost effective compared to the existing commercialized devices and is portable but it is limited only to the users who have smartphones and to see the notification can be delayed which makes it complicated.

A piece of work by Ferdews Tlili et al [12] surveyed sitting posture monitoring systems, they surveyed Posture monitoring systems based on pressure sensors, Posture Monitoring Systems Based on Inertial Sensors, Posture monitoring systems based on flexible Sensors, Posture Monitoring

Systems Based on inductor Sensors and Posture Monitoring Systems Based on Optical Fiber Sensor. To know the functionality of each system during the survey each methodology in each system was reviewed. Posture monitoring systems based on pressure sensors based on pressure sensors that are inserted at backrest plate and seat plate and provide the information related to weight distribution of the users. The system is also composed of inclinometer sensors placed on the neck, weight sensors are attached to feet, then all systems analyze weight information and define the sitting postures. The researcher described a major limitation of the system is that it always requires a specific environment outfitted with the load cells in an office and this is complicated to be applicable everywhere.

Another reviewed system is Posture Monitoring Systems Based on Inertial Sensors, inertial sensors provide information about the tilting and linear acceleration due to its tiny size and highly portability characteristics enabling them to be incorporated directly into people clothing, inertial sensors attract attention of many researchers in field of industrial, medical and aerospace. In the posture monitoring system inertial sensors monitor spinal curvature during the trunk movement on the sagittal and coronal planes, inertial sensors had shown great impact in piece of work by Q.Wang [13] during designing Smart Rehabilitation Garment for posture monitoring.

While using inertial sensors in Smart Rehabilitation Garment for posture monitoring, the vibration feedback is given to the user through A LilyPad Vibe Board when a user sits in the wrong position. Another related piece of work based on the inertial sensor by A. Fathi [14] uses a combination of the inertial sensor, E-Textile sensors, and Fiber-optic bend sensors. The combination of those sensors aims to detect accelerometer and gyroscope data therefore when a user changes direction those data are analyzed then the user is notified. To conclude, the researchers described that posture Monitoring Systems Based on Inertial Sensors are characterized by high portability and the system's measurement accuracy is sensitive to the sensor's position.

Posture monitoring systems based on flexible Sensors are also evaluated, flexible sensors are made in malleable materials without changing their properties. A flexible sensor is based on polyvinylidene fluoride which acts as piezoelectric material whose resistance changes in case of sensor bent. A reviewed piece of work was “Real-Time Monitoring of Posture to Improve Ergonomics Donne” by M. Gopinath [15]. The system is based on a flexor sensor attached to the thoracic region to provide/ detect the bending angle of the user.

Figure 2.7 shows the block diagram of the posture monitoring system by using flexible sensors. A researcher described that the flexor sensors are sensitive to the sensor position and are characterized by high sensitivity to define the shape, curvature and small bent angle [15].

A piece of work by F.Tlili et al [16] also reviews the posture monitoring systems based on inductor sensors, inductor sensors measure inductance as results of geometric deformations this deformation arises due to lengthening and straightening of the body. In case inductor sensors used to monitor posture are stuck on the spine and then sensor elongation variation tells the implication about the spine Spinal morphology. Inductive sensors have been used in a piece of work of Emilio Sardini et all [16], they designed posture monitoring T-shirts used for rehabilitation exercises based on inductor sensors. The system is made of one inductor sensor tacked on the T-shirt and throughout the user's back and chest. As demonstrated in Figure 2.8 the inductor sensor elongates when the user changes positions and those variations in elongation cause variations in the sensor's inductance.
Posture monitoring T-shirts used for rehabilitation exercises based on an inductor sensor also uses two vibro-feedback sensors to alert users in bad posture cases. The researcher described the advantages of inductor sensors in posture monitoring but are limited on sagittal geometric deformation and, therefore, do not give the information when the user is inclined left or right [12].

Posture Monitoring Systems Based on Optical Fiber Sensor are also reviewed. The optical fiber sensor is composed of light sensors and a light source. The curvature of the fiber is influenced by the quantity of light observed between the light emitter and the light detector. Posture monitoring based on fiber sensors uses a light source and a light sensor stuck to the two optical fiber ends. One of the developed systems is A System for Wearable Monitoring of Seated Posture in Computer Users by Dunne et al [17], a wearable plastic optical fiber sensor for monitoring seated spinal posture is used. A system is composed of Fiber-optic bend, bend sensor inserted in Optical sensor shirt.
The posture monitoring system based on optical fiber demonstrates its sensitivity to the sensor position and any slippage of optical fiber position leads to inaccurate posture evaluation. To summarize the survey on posture monitoring systems, it is concluded that many systems are based on pressure sensors, inertial Sensors, flexible Sensors, inductor Sensors, and optical Fiber Sensor. Pressure sensor-based systems do not meet portability requirements but inertial sensors, flexible sensors, inductor sensors, and fiber optical sensors do. The inertial sensors are sensitive to the sensor position and orientation. The flex sensors and optical fiber-based systems accuracy is related to the sensor position therefore the poor postures are not detectable when the sensors are placed on the lumbar or the lower thoracic.

POSTURE MONITORING SYSTEMS ARCHITECTURE

Table 2. 1: Summary of the current previous related works.

Papers	**Types of sensors**	**Information provided by sensors**	**Number of sensors**	**Sensor's placement**
Jingyuan Cheng et all.2013[18]	Pressure sensors	The total weight and the distribution of weight and force exercised to the four legs	4	Under chair legs
Roh J et all.2018[9]	Load sensors	Body weight ratio	4	Mounted on the seat plate
Jullia Birsan et all.2017[19]	Pressure sensors	Weight distribution	11	9 pressure sensors on the pillow and 2 pressure sensors on the back
Bilal El-Sayed.2011[20]	Inclinometer Sensor and load sensors	Posture angle and weight	3	The inclinometer sensor positioned at the neck + load sensors placed on the feet soles
Wai Yin Wong et all.2008[21]	Inertial sensors: 13D accelerometer and 3 gyroscopes	Tilting angles and trunk angles of the thoracic and lumbar regions	3	Sensors embedded on the garment on the upper and trunk and in the pelvic level
Q. Wang et all.2015[13]	Inertial sensors	Thoracic angle	2	Vertebrae T1 and T5 of spine
Azin Fathi, Kevin Curran.2017[14]	Inertial unit: ac-accelerometer and gyroscope	Acceleration and angles change rate	3	Cervical spine, thoracic spine and lower lumbar spine.
Maheswaran Shanmugam et all.2018[22]	Gyroscope and Accelerometer	Acceleration angle con-verted to the bend angle	1	The sensor unit is placed on the lower back or at the shirt pocket.

Da-Yin Liao.2017[23]	Accelerometer	Tilt angle	1	Earhook device
Harsh Gupta.2018[24]	Accelerometer	Tilt angle	1	Smartphone accelerometer
Manju Gopinath and Angeline Kirubha.2015[15]	Flex sensor and cell load	Voltage value caused by resistance variation during spine bending and body load	2	The Flex sensor placed on the mid-thoracic region and the load cell is placed be- tween platforms on which the subject can stand
Emilio Sardini et all.2015[16]	Inductive sensor	Inductance value	1	sticked to the T-shirt throughout the patient back and chest
.E. Dunne et all.2007[17]	Plastic optical fiber (POF) sensor	Bend degree	1	Plastic optical fiber (POF) integrated into the garment. A light source and light sen- sors are placed at the edges of the POF. The POF is stuck to the subject back
Jawad Ahmad , Johan Sidén and Henrik Andersson[25]	Pressure sensor	Weight distribution	4	At wheelchair seat
Chaitanya Kumar A1,and V G Sridhar[26]	Tilt,temperature, pulse and pressure sensors.	Tilt angle	3	Pressure sensor placed at smart chair seat while tilt sensor at neck.
Mritha Ramalingam[27]	Gyrometer, Pressure and Ultrasonic	Tilt angle	2	Tilt sensor on headphone Ultrasonic sensor

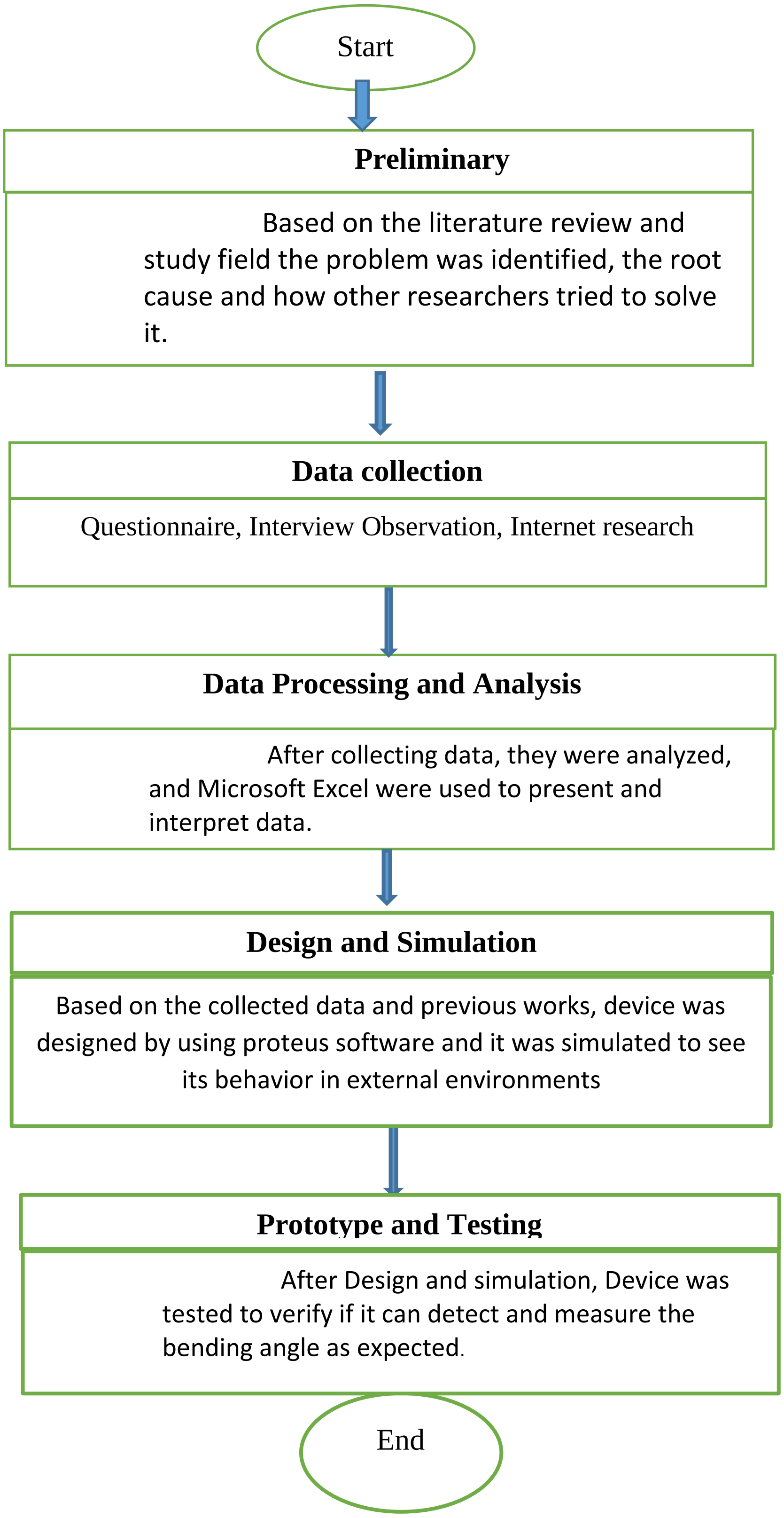
	Sensor.			on seat And headset
Gizem Özgül and Fatma Patlar Akbulut[28]	Accelerometer sensors	Tilt angle	2	In the Vest

Literature shows what different researchers have done about musculoskeletal disorders arise due to long sitting hours in poor position; by using different approaches and techniques Those devices have more benefits however, they have some limitations based on such as high-cost, low accuracy and high technology that can be accessible on low-income people like students. This research work proposes a high accuracy, low-cost device that can be used in a variety of settings, including schools, offices, churches where many people can take a long time while sitting.

CHAPTER 3. RESEARCH METHODOLOGY

3.1. RESEARCH PROCESS.

This section summarizes the methods and approaches used to conduct the study and the sequence of how the research conducted from the beginning towards the end; this includes data collection, data analysis, device design and simulation, prototyping and testing.



3.1.1. DATA COLLECTION

During data collection, the objectives, firstly was to identify the normal sitting positions and bad sitting positions, secondly was to know the mostly sitting positions office workers use, and lastly is to know whether they would like to use the proposed sitting posture monitoring system.

I. Bad sitting positions

The purpose was to know the bad sitting posture angle so that a developed device can be trained based on that angle. To know the bad sitting posture, it was differentiated from normal spine curve and the posture, which is out of the range, is considered poor positions. Bad sitting positions were distinguished by considering approximate normal range of spinal curve, as illustrated in Table 3.1 shows is cob angle measured in each section of the spine.

Table 3. 1: Approximate normal human curve.

Spinal Section	Approximate Normal Range
Cervical(lordosis)	19.4^0-21.4^0
Thoracic (kyphosis)	45.1^0-49.0^0
Lumbar(lordosis)	39.7^0-40.0^0
Sagittal plane Deviation (Torsion)	$\sim 0^0$

Office workers sitting positions.

To know the sitting positions of the workers during office, observation methods were used, randomly 10 workers at the company called tek-Experts as a leading, global provider of business and IT support services, and a developer of technologies that enhance the customer experience by enabling their teams to work more effectively. Some of the workers were observed during the office time, the observation time was 15 minutes, and their behavior was recorded during that time.

- **Scoliosis posture**: the workers sit, right leg above left leg or left leg above right leg.

Figure 3.1: Scoliosis position.

- **Lordosis posture**: worker bends outwards at lumbar.

Figure 3.2: Lordosis posture.

- **Hyper-kyphosis posture:** legs and head are very close.

Figure 3.3: Hyper-kyphosis posture

- **Hypo-kyphosis posture:** legs and head are apart.

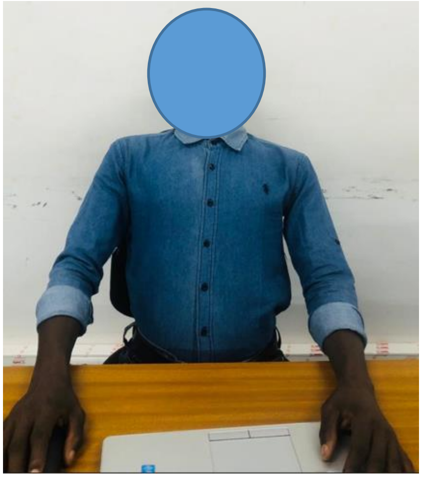


Figure 3.4: Hypokyphosis posture.

The summary of the obtained results is shown in Figure 3.5.

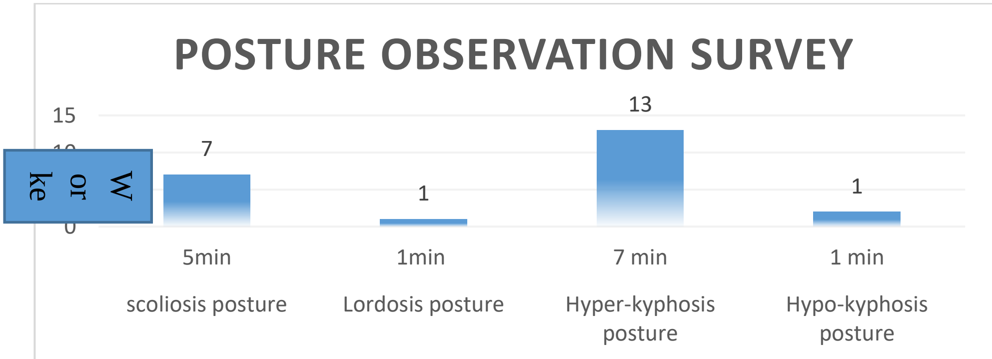


Figure 3.5: Survey on sitting postures.

II. The user's perspectives

During data collection about the users' perspectives, questionnaire and interview was used in collecting data, Engineers at tek-experts ltd were asked and the objectives was to know the effect of spending long time sitting in the office during works and to know how they think about how smart monitoring system can be helpful to prevent those effects.

Engineers at Tek-Experts Ltd work 9 hours per day including one hour of break, because of tough work they have, some of them spend 4 hours sitting on office chairs. The 20 workers (Male and female, youth and adults, new and ancient workers) are included in the study sample. Workers with at least one year of experience were asked how he/she felt before and after starting to work such kinds of work in terms of excess pressure on the spine, lower back pain. Also, the workers were told about the proposed system with the purpose of their feedback, by using interview and google forms each answer was recorded and the results are summarized on Figure 3.6.

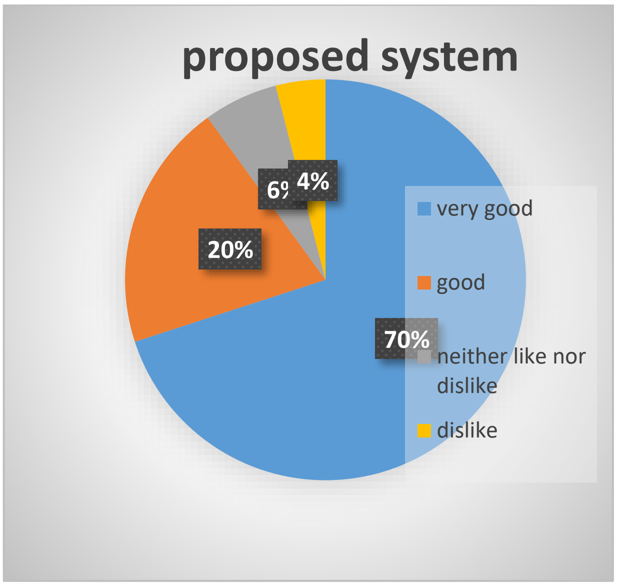


Figure 3.6: Results of the user's perspectives.

Based on collected data shows that most of the office workers spend a long time sitting in poor positions and this has negative impacts on their health especially the musculoskeletal system to combat this the proposed real time poor sitting posture-monitoring system the users believe that the system has advantages in bad posture corrections. Based on the collected data, a smart posture monitor system is designed.

II.2. DESIGN OF SMART POSTURE MONITORING SYSTEM

II.2.1. Block diagram.

Smart posture monitoring system detects poor sitting posture by using flexor sensors (bending sensors) and alert the user through buzzer, led and vibrator and the data are saved at thingspeak for future use. The recommended sitting posture (angles) and the bad sitting position are recorded and processed in the microcontroller. Figure 3.7 shows the block diagram of the whole system.

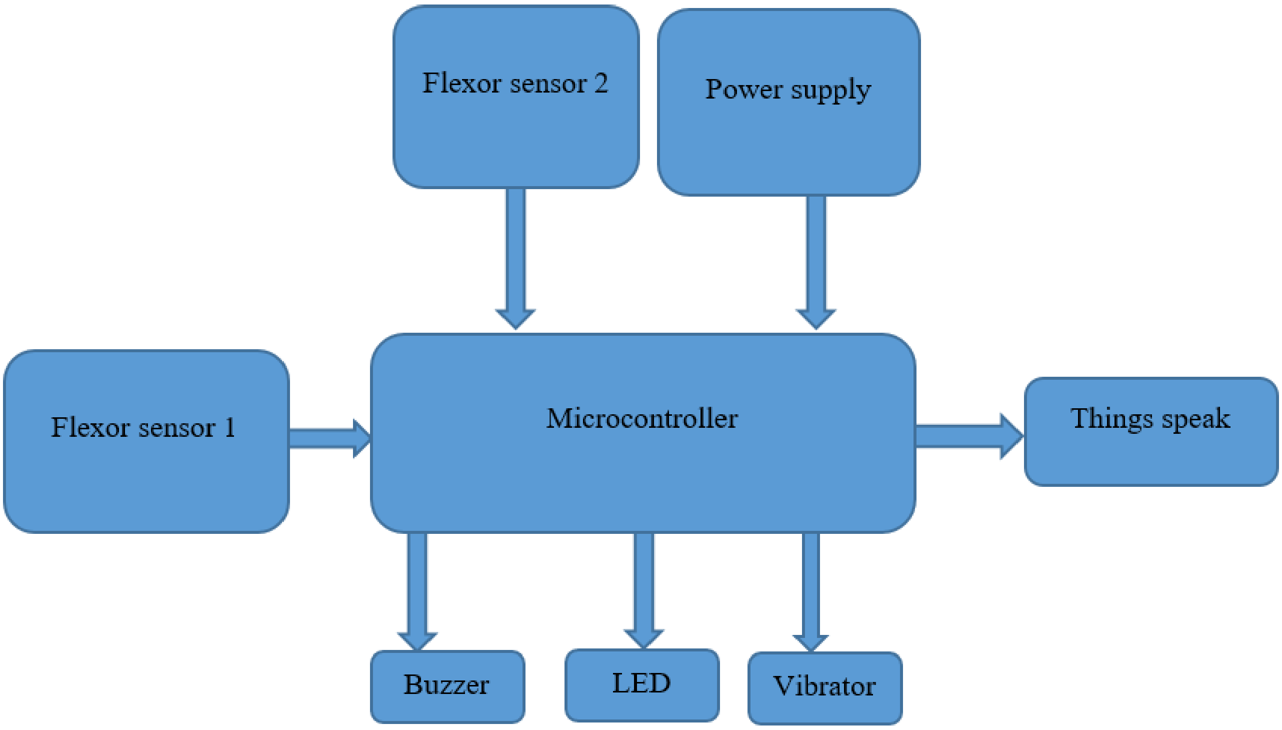


Figure 3.7: Block diagram of smart sitting posture monitoring system

II.2.2. Material selection

This section describes the materials used to design the smart wearable posture monitoring system. Materials are grouped into three categories: sensing, data processing and alerting system.

1. **Flexor sensors**

A flex sensor or bend sensor is a sensor that measures the amount of deflection or bending. Usually, the sensor is stuck to the surface, and resistance of the sensor element is varied by bending the surface. This method of sensing has many advantages over current carbon-based sensors including linear output, ability to make two sensors with identical output (nearly impossible with carbon-based sensors), reduced hysteresis, improved accuracy, and reduced power consumption, flex sensor experiences high sensibility to the small change as a desired feature needed during designing Wearable Smart Device for Sitting Posture-Monitoring System [29].

The flexor sensor is available in two-size 5.588cm long 11.43cm long as illustrated in Figure 3.8.

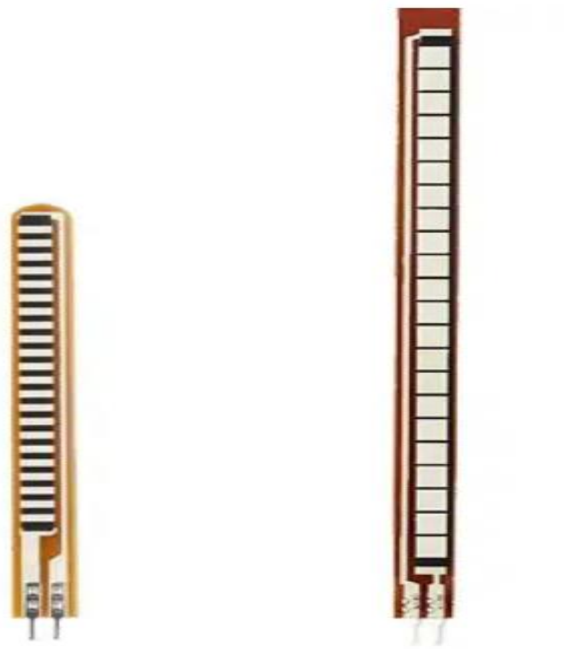


Figure 3.8: Flexor sensors.

The wearable smart posture monitoring system uses 11.43cm due to its large length which is large enough to be used when human bends. Table 3.2 shows the technical specifications of the flex sensors.

Table 3. 2: Technical specifications of flex sensors

SN	Items	values
1	Height	11.43cm
2	Flat resistance	25K Ohms
3	Operating temperature	-450C to 800C
4	Bending range	25K to 125K Ohms
5	Operating value	0-5V

2. NodeMcu ESP8266

Data are processed in microcontroller, smart posture monitoring uses the NodeMcu ESP8266 WIFI Internet Development Board BRD51, R11due to its ability to transfer data from device to the cloud and also its cost effectively, lightweight and easily to operates [27].

Figure 3.9: NodeMCU.

Features of NodeMcu ESP8266 WIFI Internet Development Board

- Use CH340G to replace the CP2102.
- Open-source, Interactive, Programmable, Low cost, Simple, Smart, WI-FI enabled.
- Arduino-like hardware IO
- Advanced API for hardware IO, which can dramatically reduce the redundant work for configuring and manipulating hardware.
- Code like arduino, but interactively in Lua script.
- Nodejs style network API
- Greatly speed up your IOT application developing process.
- Wi-Fi MCU ESP8266 integrated and easy to prototype development kit.

3. **<u>Buzzer</u>**

Buzzer in smart posture monitoring system works as an alert when the user sits in bad posture.

Figure 3.10: Buzzer.

Features of buzzer

- Input Voltage (Max.): 5V.
- Resistance: 90 Ω
- Resonance Frequency: 2048 Hz [30].
- Sound pressure(dB(A)/10cm) min.: 80.
- Body Size: 12 x 9.5mm
- Pin Pitch: 6mm.

4. **LED 3mm Red Color Light Super Bright**

Led also give an alert when the user sits in bad posture, it has 3mm LED with RED as it's emitting color [31].

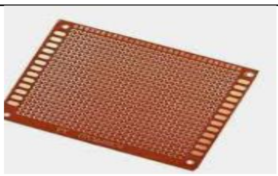
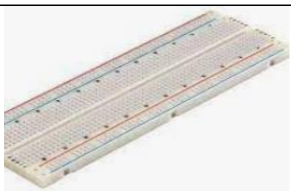
Figure 3.11: LED.

5. **Vibrator**

Vibrators vibrate when the user sits in the angle greater than the threshold value.

6. Accessories

Table 3. 3: Accessories

SN	Parts	Image	Specifications	Functions
1	Batteries		Rechargeable 3.7V	To supply the system
2	Resistor		47kΩ	To limit the current
3	Jump wires		Low resistance	To carry current
4	PCB			Provide base for soldering
5	Bread board			Used to make tempo
6	USB Cable			To transfer data from computer to NodeMcu.
7	Power switch			User uses power switch to select the types of alerts.

II.2.3. CALCULATION OF THE THRESHOLD VALUES

Calculations of the threshold values are based on the working principle of the flexor sensor and findings on normal human spine curves.

a) Working principle of the flexor sensor

The device has a deposition of conductive ink on a phenolic resin substrate. In addition, the top of the device has a segmented conductor that helps generate a flexible potentiometer. With this, the resistance changes with deflection. Figure 3.12 illustrates the working principle of the flexor sensor.

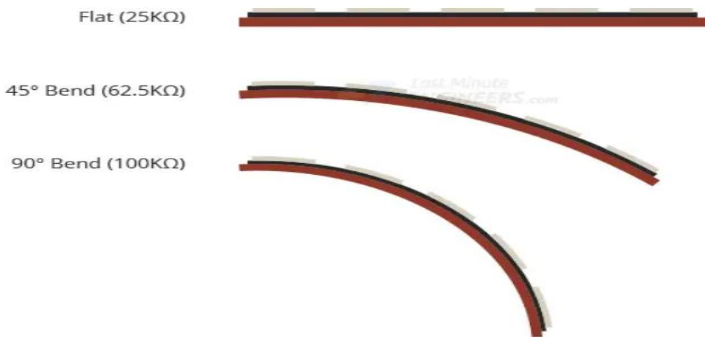


Figure 3.12: Flex sensors.

When the user bends at a certain angle the resistance of the flexor sensor increases, as it increases the measured voltage drops whoever the threshold value of voltage is needed to differentiate normal sitting angle from abnormal sitting position. To set the threshold value the relation between the angle and voltage is established. During designing smart wearable posture monitoring system flex sensor is connected in series with 2.2KΩ, and then the supplied by the 5V, then the voltage dropped in the flexor sensor is detected.

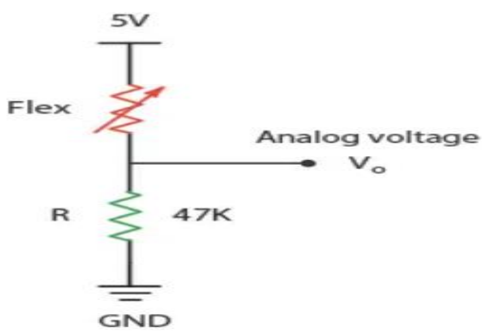


Figure 3.13: Measurement of analogy value

So, the output voltage is given by:

V_0=5 $* R/(R + Rflex)$

With reference to the work done Ashlyn J. M and his colleagues [32], the relation between the cobb angle and the tangent angle to the spine is established and is given as below.

$\alpha = \frac{1}{2}\beta$ Where α: $tangent\ angle\ to\ the\ spine\ curve$ while β: $cobb\ angle$

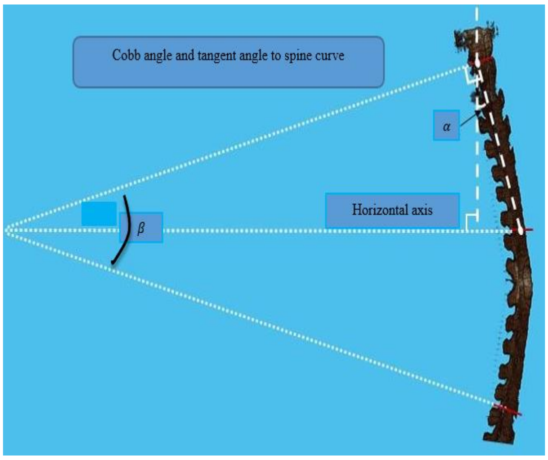


Figure 3.14: Human spine and cob angle.

Now let calculate the tangent angle corresponding to the hyper-thoracic kyphosis, range for hyper-thoracic kyphosis is cobb angle below 45.

β =45.10, then α =$\frac{45.1}{2}$=22.5^0

Bending(flexor) sensors at the thoracic region detect angle below 22.50 as hyper-thoracic kyphosis sitting position while the bending angle in sagittal must be zero for good positions. On the other hand, the Bending(flexor) sensor at the lumbar region will detect angle above 0^0 as scoliosis position.

Angle is obtained by using analog to digital converter where the minimum voltage is mapped to zero degree while maximum voltage is mapped to 90 degrees as the maximum bending angle of the flexor sensor.

b) <u>The position of the sensors on body</u>

Two flexor sensors are used during designing the smart posture monitoring system. The first sensor is used to sense the bending angle at lumbar level while the second sensor is used to detect bending angle at thoracic level. The wires are connected to the sensors to ensure the good positioning of the sensor at the right position. The spine is drawn in Wondershare EdrawMax software.

II.2.4. <u>COMPUTER AIDED DESIGN</u>

Computer aided design aims to develop the virtual system of wearable posture monitoring system.By using software of proteus 8 professional, the system is designed as illustrated in Figure 3.17. System is composed of Arduino Uno, Global system for mobile communication, flexor sensors, resistor, and batteries.

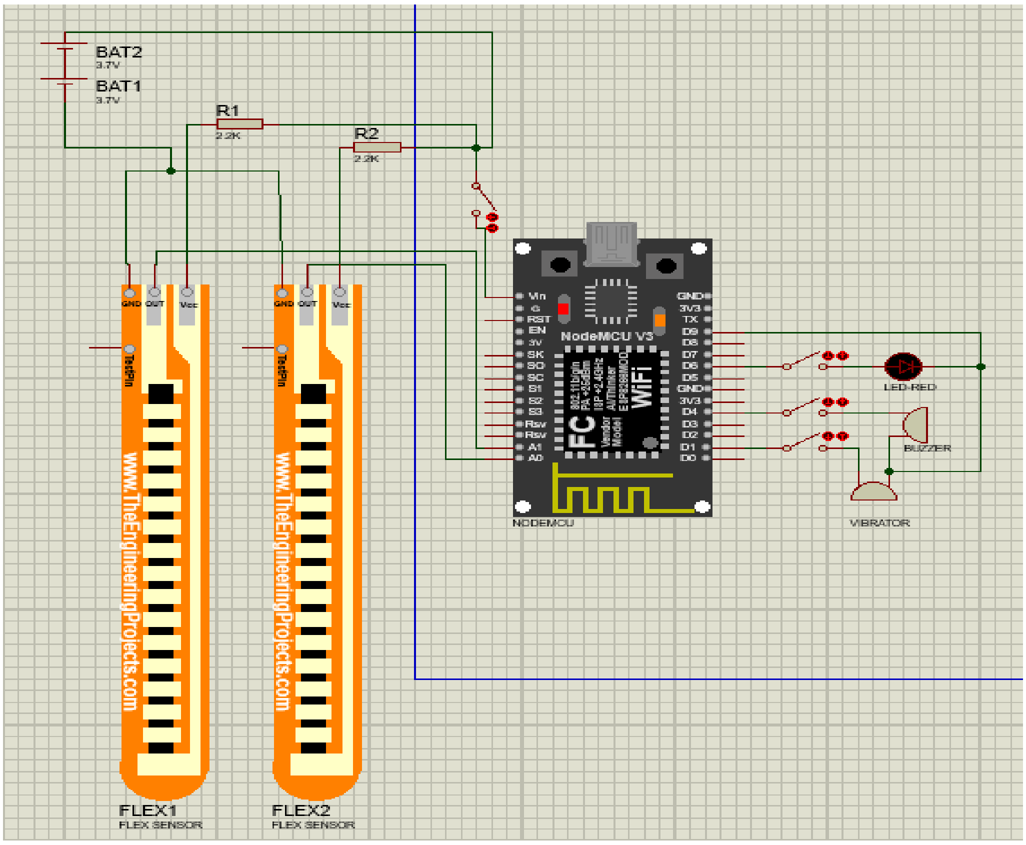


Figure 3.16: Electric Circuit of the system

IV.2.6. <u>PROTOTYPING</u>

Prototyping refers to assembling hardware to get the final product. During prototyping the posture monitoring system, the first step was to make a temporary circuit on breadboard. and then the final (soldered circuit) is designed.

i. Smart sitting posture monitoring on breadboard

By using a breadboard as a building base, devices are assembled to see whether all devices are functioning before making the soldering, as illustrated in Figure 3.18.

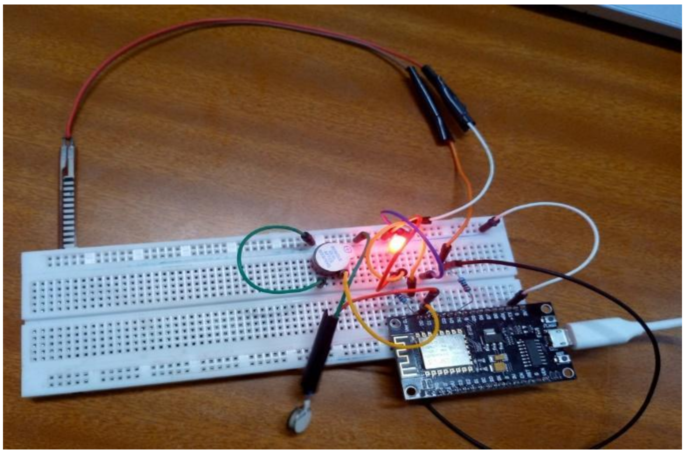


Figure 3.17: System on breadboard.

To test the functionality of the device the flexor sensor is bent if the sensor value to microcontroller greater the threshold value Led light on, buzzer gives an alarm by sound and vibrator vibrates.

ii. Smart sitting posture monitoring on soldered circuit

To make the permanent circuit a switch is also introduced in the circuit to allow the user to choose the alerting system.

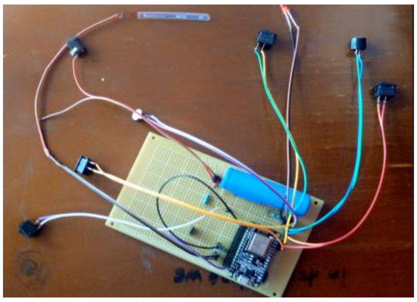


Figure 3.18: System on the printed circuit board.

iii. Casing

The device is covered by using cartons and the stickers used to cover the cartons.

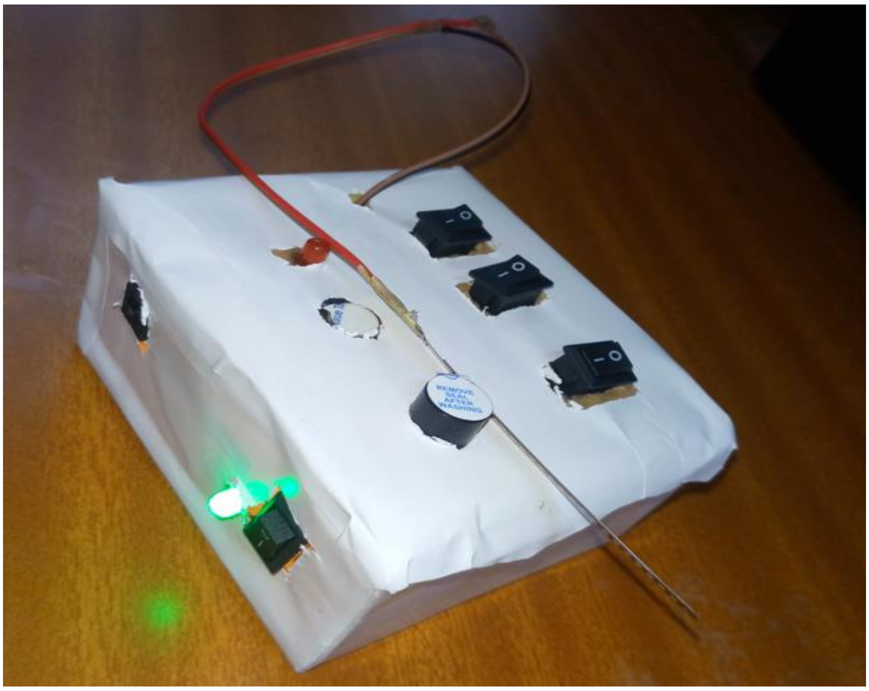


Figure 3.19: Smart sitting posture monitoring system.

External features of the smart sitting posture monitoring

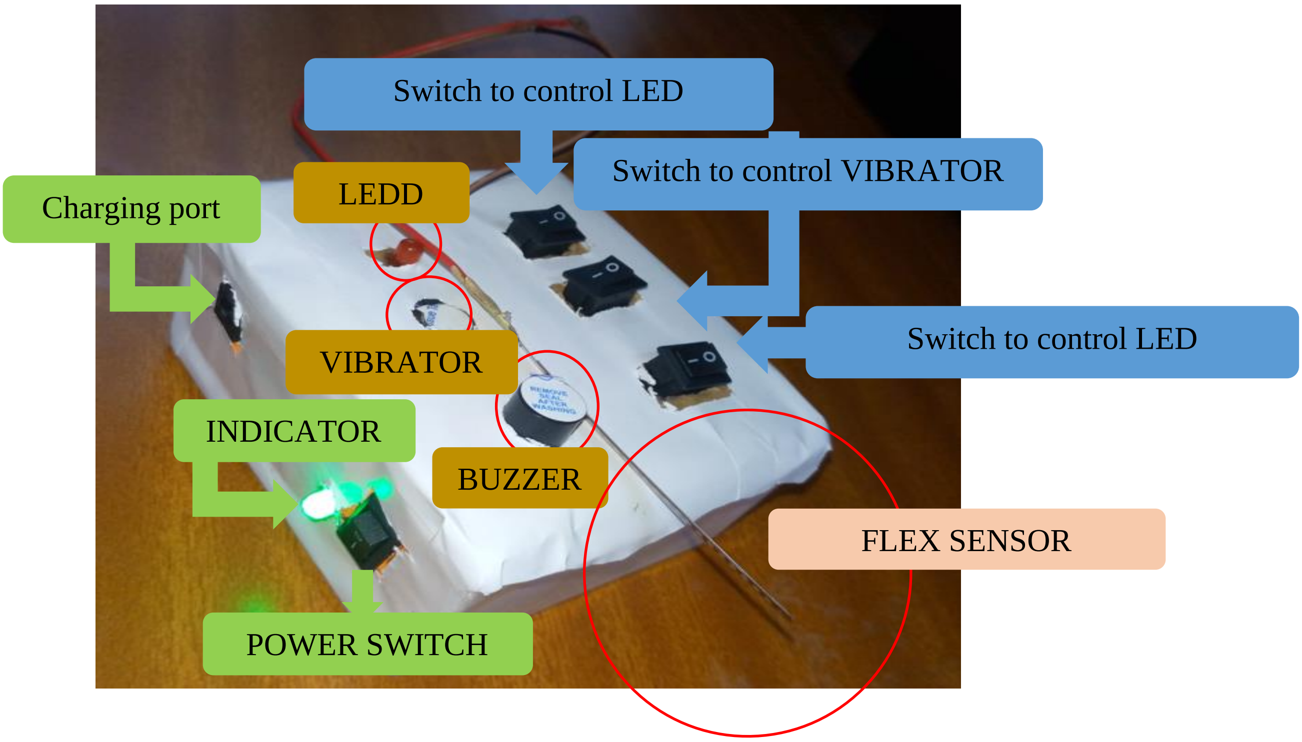


Figure 3.20: Features of smart sitting posture monitoring system.

Figure 3.21 shows the external components of the Sitting Posture-Monitoring System grouped in four categories such as powering system, sensing part, control switches and powering system.

i. SENSING PART

The functioning of the system is based on the sensing system, without the proper operation of the sensing parts a device will not deliver any role and all things start on the sensor.

a. **Flexor sensor**: Wearable Smart Device for Sitting Posture-Monitoring System uses a flexor as a sensing element that detects poor sitting position by monitoring the bending angler of the user.

ii. ALERTING SYSTEMS

Wearable Smart Device for Sitting Posture-Monitoring System has three types of notification systems when user a user sits in kyphosis or scoliosis positions, and a user is allowed to choose a favorite means of being notified of alerting through a controlling switch, the components of alerting system are listed follow.

- **Buzzer**: Using sound, the buzzer indicates that the user sits in the wrong position.
- **Led**: By utilizing a red light from the LED as an indicator, the user gets notified when sitting in the wrong posture.
- **Vibrator**: Vibrator also vibrates when the bending angle exceeds the allowed bending angle.

iii. CONTROL SWITCHES

A user has the option to choose the best way to get a notification by switching on his/her favorite alert between sound, vibration or light, this is achieved by using the indicated switch on Figure 30 to switch on/off the alerting system.

iv. POWERING SYSTEM

a. **Power switch**: A power switch is used to turn the current from the battery to microprocessor.

b. **Charging port**: Wearable Smart Device for Sitting Posture-Monitoring System is supplied by battery; a battery is discharged after the same time during operation however it gets charged through the charging port.

c. **Blue-Led:** BLUE light from the LED as an indicator tells that the circuit is closed (current follows from battery to microcontroller).

<u>Internal features of the system</u>

The main internal component of the smart posture monitoring system is NodeMcu ESP8266 WIFI Internet Development board used to control all hardware parts, to control the other parts the system software is developed in Arduino UNO and is embedded in NodeMcu. The system software is developed so that it takes the analogy value from sensor convert into the digital signal when the signal exceeds threshold value digital pins of microprocessor D2, D5 and D7 become high then alerting equipment gets powered. Also, the system sends the data to a dashboard of the user. Smart posture monitoring system sends data to the dashboard of the user and data is monitored and saved on the Thingspeak platform. Therefore, the Channel ID and write API key of the thingSpeak's user dashboard is inserted in program codes to receive the captured data. The used codes to develop system software are shown in APPENDIX 2.

COST ESTIMATION OF DEVICE

Table 3.4: Cost estimation of the Posture monitoring system.

SN	COMPONENTS	PRICE
1	NodeMcu	15000
2	Flex sensor	20000
3	Switches	2000
4	Vibrator	3000
5	Battery	15000
7	Printed circuit board	1000
8	Jumper wires	2000
9	Other expenses	20000
TOTAL		**75000**

IV.3. SUMMARY

This section summarizes the steps taken in methodology during designing a wearable smart device for sitting posture-monitoring systems. First, a review of the available sitting posture-monitoring techniques is carried out to identify the gap that needs to be filled. After reading through several papers on the subject, it is discovered that most sitting posture monitoring systems are not portable, which makes them difficult to use and expensive. As a result, a wearable smart device with enhanced functions over the existing one that is also reasonably priced for many users is required for the sitting posture monitoring system.

Secondly, once the key elements have been identified, data collecting is carried out to determine whether the suggested approach is required. During data collection, the approximate normal range was found to be 19.40-21.40 for cervical (lordosis), 45.10-49.00 for thoracic (kyphosis), 39.7-40.00 for lumbar (lordosis), and sagittal plane deviation of 00. Bad sitting posture is identified from the typical human curve using secondary data. As a result, office employees' sitting positions are observed utilizing the observation method to determine how they sit while at work. 22 workers made up the sample size for the data collection at Tek-Expert. The findings indicate that throughout the 15-minute observation period, 59% of workers spent 7 minutes sitting in the hyperkyphosis position and 32% spent 5 minutes sitting in the scoliosis position.

Thirdly, the next step involved choosing materials and prototyping devices; this entails finding reliable, accurate, and reasonably priced devices. The wearable smart device for the sitting posture-monitoring system uses a flexor sensor as its sensor, which has high accuracy because it is highly sensitive to even slight changes. The microcontroller (NodeMcu), which can process and transmit data to Thingspeak, is therefore selected to alert the user when they are sitting in the incorrect position. The device is designed and prototyped and it uses alerting devices like a vibrator, buzzer, and LED to notify the user with vibration, sound, and light, respectively. The device is cost-effective and affordable compared to the existing posture monitoring system.

CHAPTER 4: PERFORMANCE ANALYSIS AND DISCUSSIONS

Smart sitting posture monitoring system designed with regard to all procedures to ensure that device is working properly and gives desired results including Real time monitoring of sitting posture, Alerting the users sitting in bad positions and sending the data.

4.1.TESTING

To test the functionality of the device, it is tested on both positions (hyper-kyphosis positions and Scoliosis). Figure 4.1 (left) shows the flexor sensor positioned on the user at the sagittal plane to detect if the user bends leftwards while Figure 4.1(right) shows the flexor sensor positioned at back, in the thoracic region to detect if the user bends inwards.

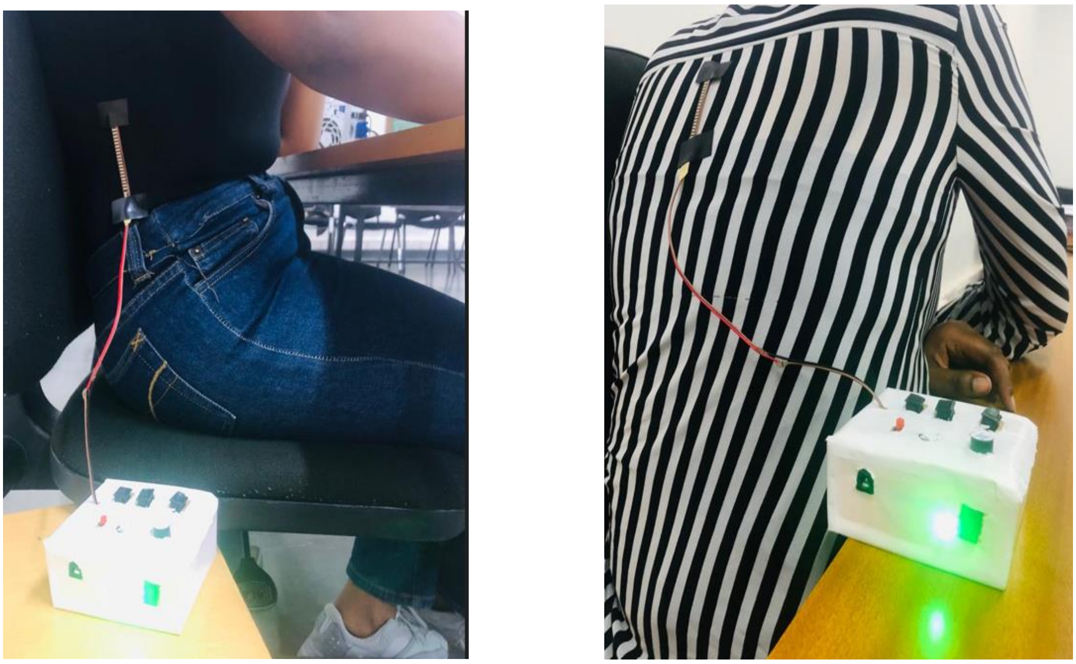


Figure 4.1: Testing the device on scoliosis position (left) and kyphosis (right).

Testing procedure

a) The smart device for monitoring sitting posture has brought the user closer: the device is getting closer to the user so that a flexor sensor can be accurately positioned on spine and on sagittal position.
b) The flexor sensor is positioned to the user:With using the sticker, the flexor sensor is attached to the clothes.
c) Device turned ON:By using power switch to allow current flow from battery to the microcontroller:

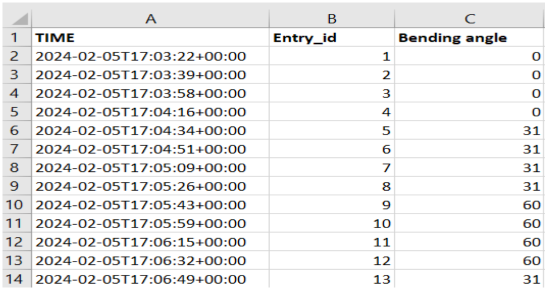
d) User asked to sit in the correct sitting position, then changed sitting angle slowly: To test the functionality of the device, the user asked to change position graduation from small angle to large angle.
e) Bending angle had been monitored on thingspeak.
f) Device has been monitored to see if it gives an alert when bending exceeds the threshold value.

4.2.RESULTS DISCUSSIONS

The results show that there are small significant changes in bending angle due to the small resolution (sensitivity) of the sensors. Due to unavailability of flexor sensors which have length of 11.43cm the used sensor of 5.588cm long does not bend enough when it is attached to the human body. To test in absence of the long flexor (11.43cm), the available flexor sensor of 5.588cm is bent by using hands. To check whether the bending angle can exceed the threshold value, as illustrated in Figure 4.2, the flexor angle bends, and all alerting methods give the notification to the user.

Figure 4.2: Testing a device with hands bending.

Figure 4.2 shows the user bending the flexor sensor by hand, during bending the bending angle exceeds the threshold value then LED light on vibrator vibrates and buzzer gives alarm. The user is granted the freedom to choose the way he/she needs to receive a notification/and alert. according to his/her environment or personal preference, if the user is surrounded by many people and doesn't want to disturb them, he/she can turn on vibration to notify him/her. if he/she doesn't mind the people surrounding him/her and need to receive an alarm notification, he/she can turn on the buzzer to receive an alarm. If he /she doesn't want either he/she can prefer to turn on the LED light. In addition, the user can use all types of notification at the same time. The results indicate that when the long flex sensor is available the sensitivity of the device can be improved so that it can detect the small change of bending of the user. On other hand, the data are monitored and stored on thingspeak as shown in Figure 4.3.



	A	B	C
1	TIME	Entry_id	Bending angle
2	2024-02-05T17:03:22+00:00	1	0
3	2024-02-05T17:03:39+00:00	2	0
4	2024-02-05T17:03:58+00:00	3	0
5	2024-02-05T17:04:16+00:00	4	0
6	2024-02-05T17:04:34+00:00	5	31
7	2024-02-05T17:04:51+00:00	6	31
8	2024-02-05T17:05:09+00:00	7	31
9	2024-02-05T17:05:26+00:00	8	31
10	2024-02-05T17:05:43+00:00	9	60
11	2024-02-05T17:05:59+00:00	10	60
12	2024-02-05T17:06:15+00:00	11	60
13	2024-02-05T17:06:32+00:00	12	60
14	2024-02-05T17:06:49+00:00	13	31

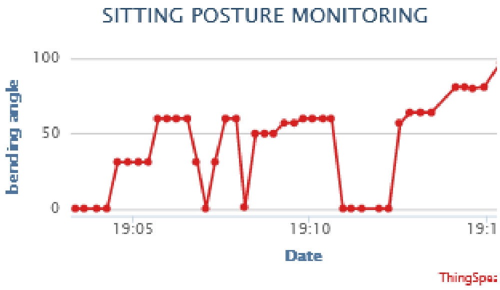


Figure 4.3: Data monitored on thingspeak (left) and stored in Database (right)

Comparison of wearable posture monitoring system with other existing methods.

The comparison is based on the cost and accuracy of the device. The cost of the existing methods is estimated based on the components made.

i. Cost comparison

As illustrated in Table 3.4 the cost of wearable posture monitoring system is estimated to be 75,000 Rwf by comparing the cost of other existing methods shown in table 4.1, the cost of the designed system is lower than the existing method and makes it to be cost effective compared with other methods.

Table 4. 1: Cost of others existing methods

SN	Monitoring system	Cost (Rwf)
1	Posture Monitoring Systems Based on Optical Fiber Sensor	150,000-180,000
2	Posture monitoring systems based on pressure sensors	200,000-200,000
3	Posture Monitoring Systems Based on Inertial Sensors	350,000-400,000
4	Posture Monitoring Systems Based on Inductor Sensors	270,000-330,000

ii. Accuracy

Due to the unavailability of the perfect flexor sensor, the used sensor of short length limits the accuracy of wearable posture monitoring system, in case the required length of the flexor is available the accuracy is expected to be higher than the existing method because the literature shows that the Posture Monitoring Systems Based flexor Sensors have high accuracy.

4.3. SUMMARY

This section summarizes the steps taken during testing of wearable smart devices for the sitting posture-monitoring system. The research design process of the wearable smart device for the sitting posture monitoring system is covered in Chapter 3. Unfortunately, the correct flexor size of 11.43 Cm was not available on the market; instead, a 4.3 cm long flexor sensor was employed. During testing, when a flexor sensor is bent with the help of hands the device alerts the user if bend angle exceeds the threshold angle; however, when the flexor sensor is tested in a real-world setting and stacked on the user's clothing, its small size results in low sensitivity this led to the low accuracy of the device. To overcome that issue in future works it is recommended to use the right flexor sensor of at least 11.43 Cm length.

CHAPTER 5: CONCLUSION AND FUTURE WORKS.

5.1. CONCLUSIONS

The smart sitting posture monitoring system represents a significant advancement in promoting spinal health and preventing discomfort or potential health issues associated with poor sitting posture, specifically kyphosis and scoliosis. By leveraging cutting-edge technology, the system monitors and analyzes the user's sitting position in real-time, providing timely alerts and encouraging corrective actions.

Key Features:

Real-time Monitoring: The system continuously monitors the user's sitting posture, utilizing advanced sensors or computer vision technology to accurately detect hyper-kyphosis and scoliosis positions.

Alert Mechanism: When the system identifies a poor sitting posture, it promptly notifies the user through customizable alerts. These alerts can be in the form of gentle vibrations, visual cues, or even reminders via a connected mobile application.

User-Friendly Interface: The system should feature a user-friendly interface, ensuring easy setup, calibration, and customization of alert preferences. This makes it accessible to users of all ages and technological backgrounds.

Data Logging and Analysis: The system may log posture data over time, enabling users to track their sitting habits and improvements. This data can be valuable for users seeking long-term posture correction and can also be shared with healthcare professionals if necessary.

Customizable Settings: Users should have the ability to customize alert thresholds, sensitivity levels, and the frequency of reminders, allowing for a personalized experience based on individual needs and preferences.

In conclusion, the smart sitting posture monitoring system serves as a proactive solution to address kyphosis and scoliosis, promoting spinal health awareness and encouraging users to maintain a more ergonomic and comfortable sitting position. This innovative technology aligns with the growing emphasis on preventive healthcare measures and contributes to overall well-being in daily life.

5.2. FUTURE WORKS.

The designed smart sitting posture monitoring system uses the flex sensor of 4.33 cm, which has low sensitivity to the bending angle for the future researchers are recommended to design the long flexor sensor, which has large enough sensitivity to detect small changes of bending angle.

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APPENDICES

1. SURVEY QUESTIONNAIRE

Please complete and submit this survey questions, we estimate that it should take no more than 10 minutes.

1. What is your age range?
2. How many hours per day do you spend sitting?
3. Do you currently experience any pain related to sitting for extended periods?
4. Have you ever received training on proper sitting posture?
5. Are you currently using any tools or methods to improve your sitting posture?
6. How concerned are you about developing musculoskeletal disorders due to poor sitting posture?
7. Would you prefer a wearable device or a stationary device integrated into your chair?
8. What type of notification or alerts would be encouraging you to adjust your posture?
9. Would you prefer real-time feedback or periodic summaries of your posture?
10. Would you be interested in accessing data about your sitting habits over time?

Survey Questionnaire Link: https://forms.gle/oVXsDpcjWuFzydPs9

2. USED CODES

```
#include <ESP8266WiFi.h>
#include <ThingSpeak.h>

const char* ssid = "Nady";
const char* password = "1234567890";

#define sensorPin A0
#define buzzerPin1 D2
#define vibratorPin D6
#define buzzerPin2 D7

unsigned long myChannelNumber = 2413891;
const char * myWriteAPIKey = "76Y0NE1653X4ONMB";

WiFiClient client;

void setup() {
  pinMode(buzzerPin1, OUTPUT);
  pinMode(vibratorPin, OUTPUT);
  pinMode(buzzerPin2, OUTPUT);

  Serial.begin(9600);

  // Connect to Wi-Fi
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("");
  Serial.println("WiFi connected");

  // Initialize ThingSpeak
  ThingSpeak.begin(client);
}

void loop() {
  int sensorValue = analogRead(sensorPin);
  int angle = map(sensorValue, 0, 1023, 0, 90);

  if (angle > 21) {
    digitalWrite(buzzerPin1, HIGH);
    digitalWrite(vibratorPin, HIGH);
    digitalWrite(buzzerPin2, HIGH);
  } else {
    digitalWrite(buzzerPin1, LOW);
    digitalWrite(vibratorPin, LOW);
    digitalWrite(buzzerPin2, LOW);
  }

  Serial.print("Sensor Value: ");
  Serial.print(angle); // Sending angle value
  Serial.print(", Angle: ");
  Serial.println(angle);
```

```

  ThingSpeak.setField(1, angle); // Sending angle value to ThingSpeak
  ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey);

  delay(2000);
}
```