Fit-Belt: Smart Posture & Health Monitoring

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Certificate

We accept the work contained in this report as a confirmation to the required standard for the partial fulfillment of the degree of BS(EE).

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Dedication

I would like to dedicate this project to my parents whose unconditional love, support and encouragement has been the root of all my academic and personal success. I have always been motivated to continue working and work towards excellence because of their unwavering faith in me, even when it seems like my barriers. This project is a continuation of their sacrifices and commitment to my success and I owe them all the works they have done to put me there. Thank you, you have been the strength of mine.

Acknowledgments

I would like to state my heartfelt appreciation to my supervisor, Engr. Mudasir Wahab, due to their outstanding support, guidance and expertise during my thesis. Their thoughtful comments and support have been priceless to my research and academic development. The perseverance and commitment that they have exhibited have been able to assist me in overcoming many obstacles and their guidance has played a significant role in enhancing my knowledge of the field. I owe them so much because of their unrelenting support in making me successful.

Abstract

To prevent the increasing number of concerns about posture-related health problems and particularly among students and office workers, the project will design and develop an all-encompassing, AI-based wearable device to correct posture. Sedentary posture commonly causes chronic back, neck and shoulder pain, which impacts on millions of people across the world. Classical posture aids like the Upright Go can also be expensive and proprietary, so they are not readily accessible. Our system fills this gap by incorporating real-time feedback on posture strain, and heart rate with wearable devices, such as Electromyography EMG and heart rate devices. Not only does this device monitor spine alignment but also gives individual recommendations on stress, posture, and injury prevention, which are beneficial in the long- term. The system aims to be a cost-effective, user-friendly solution for improving posture and overall well-being. Moreover, it features an AI-based platform enabling constant monitoring, feedback, and track of the progress, enabling the user to start maintaining the best posture and preventing injuries. The system will also provide the users with customized data analysis and provide corrective actions according to the real-time physiological feedback. This posture correcting solution will be highly accessible by targeting affordability, comfort and effectiveness to persons in many sedentary careers. By integrating machine learning algorithm, it is possible to make the system dynamic with unique feedback, which will improve over time and be personalized to each user, considering their individual posture patterns. Moreover, the mobile component of the system will make users monitor their progress in improving their posture and create a goal to keep them motivated and dedicated to developing their posture.

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Chapter 1

Introduction

Poor posture has become a growing concern, particularly in today's technology-driven world where many individuals spend long hours sitting for work, study, or leisure. The consequences of prolonged sitting, often without proper ergonomic support, contribute significantly to Musculoskeletal Disorders (MSDs) such as chronic back and neck pain, muscle tension, and even osteoarthritis. Conventional methods such as ergonomic seating and posture aids are useful, but do not offer personalized and real-time feedback. The purpose of the project described in this chapter is to create an AI-based posture monitoring and correction platform that will consist of wearable sensors to estimate posture, strain levels in muscles, and stress levels and provide users with real-time feedback (to maintain the correct position, prevent injuries, and generally feel better). The project is intended to fill in the missing links of the presently available solutions, and support the overall health of the population by offering them a cheap and convenient access to the tool that helps them fight the adverse effects of sedentary lifestyles.

1.1 Project Background

In this modern technology-driven world, this has necessitated many people to spend much time sitting be it at work, during studies or in leisure activities. The move towards a more sedentary way of life has taken a new dimension with the heavy use of computers, mobile devices and the other technologies that are screen based [1]. Although these technologies have come with a myriad of advantages in terms of convenience and productivity, they have also contributed to considerable health hazards, especially on poor posture [2]. Sustained sitting in bad positions adds to pressure on the spine, skeletal muscles, and ligaments, which lead to long-term back and neck pains, muscle exhaustion and permanent musculoskeletal harm [3].

The studies carried out by the World Health Organization (WHO) indicate that about 80 percent of the adult population will have reported having experienced pain in the back at some point in their lives with a good proportion of them being due to poor posture as a result of sitting long hours without supporting their posture appropriately through the concept of ergonomics. Because people are seated in their office/ workplace at least 6-8 hours daily or at their school, majority of them are immediately occupied doing their chores forgetting about their body stance, exposing them to risk of musculoskeletal illnesses. These diseases have already become a severe home-disease, and hundreds of millions of people have been infected by these diseases.

1.1.1 Technological Innovations for Posture Correction

Specifically, recent breakthroughs with wearable sensors, artificial intelligence (AI), and machine learning (ML) have helped to create metacognitive systems that are able to correct posture by continuously observing it. Most conventional posture rehabilitation tools, including ergonomic chairs and posture braces, are only passively assistive but do not offer the feedback type of assistance necessary to avoid temporary and long-lasting health problems [4]. On the contrary, wearable gadgets based on AI and Inertial Measurement Unit (IMUs) to identify the body position and poor posture have recently become popular on the market. Other gadgets like Upright Go only offer simple posture notifications when the user slouches but do not measure important physiological changes, which include muscle tension or Heart rate Variability (HRV) which are factors that cause discomfort and may result in harm [5].

The system proposed in this project aims to address these limitations by developing a comprehensive AI-powered posture correction system. It will integrate multiple sensors to continuously monitor posture, detect muscle strain, and assess stress levels in real time. The system will provide personalized feedback based on the user's unique physical condition, helping them correct poor posture in real time and avoid long-term effects associated with musculoskeletal disorders [6].

1.1.2 Musculoskeletal Disorders and Their Consequences

MSDs refer to the nature of the injury or the illness pertaining to the musculoskeletal system of the body which comprises of the muscles, bones, ligaments as well as tendons. Among these ailments; the spinal issues mostly in the lumbar (lower back) or cervical (neck) areas are the ones that are most directly influenced by poor posture [7]. Excessive sitting in poor posture may result in the excessive load on the spine and muscles around it which may cause a range of musculoskeletal conditions, such as:

- Poor posture causes the upper back and neck to be stressed, resulting in fatigue, stiffness and pain in the muscles. Over time, this can result in cervical spondylitis or other degenerative spinal conditions.

- Poor posture or sitting is equivalent to putting additional pressure on lumbar discs and this may cause degenerative disorders such as Degenerative Disc Disease (DDP). It is a disorder that results in chronic pain, stiffness, and lack of flexibility in the lower back.
- Due to poor posture, the sciatic nerve may be compressed causing sciatica, which comprises of pain, numbness and tingling at the lower back, buttocks, and legs. Compression of the sciatic nerve may also lead to irreversible damage when it is not corrected.

Moreover, bad posture causes misalignment of the spine, and this may result in deformities such as kyphosis, lordosis and scoliosis. Most of these conditions need medical correction; they can be corrected by physical therapy or surgery.

1.2 Problem Description

Despite the availability of ergonomic furniture and posture correction devices, there remains a significant gap in the market for solutions that offer real-time posture monitoring and personalized corrective feedback. Existing solutions often lack the ability to monitor key physiological parameters, such as muscle strain and stress levels, or provide real-time personalized feedback based on the user's unique needs. The limitations of current systems include:

- Inability to monitor muscle strain or stress: Many posture devices do not provide a comprehensive view of the user's physiological response to poor posture.

- Lack of personalized feedback: Current systems fail to provide feedback based on the user's specific physical condition, neglecting individual differences in posture and muscle strain.
- Limited progress tracking: Current systems lack long-term posture habits tracking and also give feedback on how a user is improving over time.
- Inaccessibility due to cost: A lot of the current solutions use costly technology thus restricting access of the same to a broader population.

This divide has brought with it the need to have a more integrated, affordable, and accessible solution with the ability not only to monitor posture but also to monitor muscle strain and stress in real-time to give feedback to the user, which can then be acted on. Our solution (a multi-sensor AI-driven posture correcting device) will help address this gap.

1.3 Project Objectives

The primary aim of the project is to create an A.I. based posture monitoring and correcting device that will involve the IMU sensors, EMG devices and heart-rate devices as a unit to check and rectify the stance of a patient in real time. The system will give a continuous and personalized feedback according to the individual posture patterns and the strain levels of the muscles. The important project goals are:

- It is proposed to develop a device that will give real-time feedback to improve spinal positioning and prevent musculoskeletal problems.
- To detect stress and muscle strain, providing feedback for posture correction, stress management, and injury prevention.

- To create a solution providing a personalized feedback and progress tracking in addition to the information about the improvement of posture over time.

1.4 Project Scope

The project development covers:

- IMU sensors will be used to monitor body alignment, EMG sensors will monitor muscle strain, and heart-rate sensors will monitor stress in the system.
- The system will give continuous feedback on posture and muscle strain, notifying users whenever they are not in good posture or when muscle strain or stress is high.
- A Graphical User Interface (GUI) will be created to display real-time data on posture, muscle strain, and heart-rate, making it user-friendly for all levels of users.
- The system will undergo extensive testing to ensure accuracy, usability, and effectiveness in improving posture and preventing musculoskeletal disorders.

Chapter 2

Literature Review

2.1 Wearable Posture Monitoring Systems

2.1.1 The Role of IMU Sensors

Inertial Measurement Units (IMUs) that include accelerators and gyroscopes are frequently used in wearable posture devices. The gadgets are critical in the process of identifying both the static and dynamic body motions, which are crucial in posture monitoring. A study by Hwang et al. (2021) highlighted the usefulness of IMUs, especially accelerometers in correcting postures. Accelerometers do sense the alteration of velocity in various directions, and help in the detection of misalignments in the body, especially in the spine. IMUs are skillful at real time posture monitoring, monitoring the angle of body parts and user motion. The information of these sensors can be transmitted to smartphone or microcontroller where algorithms are used to categorize the position of the body and give an answer back [8].

Moreover, IMUs have now been necessary because of their portability and comparative low cost. This makes them perfect in wearable devices that are small and lightweight and can be used over a long duration of time without recharging frequently. The combination of several sensors into a single wearable device has given rise to smaller, non-obtrusive devices, which are able to continuously gather data without affecting the daily routine of the wearer. The next IMU technology step, according to recent developments, would be the integration with more advanced machine learning algorithms, which can provide real-time adaptive feedback of the user based on the trends of their posture over time.

2.1.2 Posture Monitoring Devices in the Market

The market of wearable posture correction is growing fast with the integration of novel sensors and AI-based algorithms by companies. The market leaders like Upright Go and Lumo Lift are such devices that incorporate sensors to give instant feedback to their users. The gadgets mainly involve accelerometers and gyroscopes to monitor the spine position and the posture of the neck, shoulders and back. Although these devices are popular, they also have weaknesses in the accuracy of their sensors, comfort and user engagement, with many users complaining about the discomfort when wearing them over an extended duration of time which diminishes their ability to enhance posture.

Newer applications such as PosturePal and SmartBack are responding to these challenges by seeking to enhance user experience with more ergonomic designs, increased sensitivity of sensors and tailored feedback. A comparative analysis was conducted on the functioning of these devices in real-life situations by comparing the real-time data delivered by wearable devices and clinical measurements. Their results indicate that wearable posture monitors when appropriately utilized can greatly decrease the prevalence of postural deformities such as kyphosis and lordosis that are prevalent in people with long hours sitting in a seated posture. The findings promote an essential development in the field- transforming the posture correction not only into a reminder but an element of a daily routine of the user.

2.1.3 Current Research on Wearable Posture Systems

Posture monitoring wearables have developed a lot in terms of the use of machine learning (ML) and artificial intelligence (AI). Recent research has shown that using machine learning algorithms to explore the data gathered through IMU sensors, posture correction devices can learn to recognize patterns in the behavior of a user and provide more efficient feedback, which is more relevant to the user. Liu et al. (2023) applied an IMU sensor data to support vector machine (SVM) algorithm to enhance the classification accuracy of posture, which led to a more accurate poor posture detection and the minimization of false alarms [9].

2.2 The Motivation for Posture Correction

2.2.1 The Impact of Sedentary Lifestyles

One of the greatest causes of poor posture and musculoskeletal disorders is sedentary lifestyles. Sedentary lifestyle, particularly in poor office ergonomics has been associated with pain at the lower back, neck and other spine related problems. Kato et al. (2020) state that 80 percent of people will experience back pain at some stage of their existence, which is mostly caused by a long sitting posture and poor posture [10]. This is worsened by the increased remote work, where people spend days in front of computers without much knowledge of their posture.

The studies have indicated that with a prolonged sitting, the spinal misalignment is increased especially in the lumbar and cervical regions. The spine is normally built in such a way that it forms curves in certain areas and when a person sits in a prolonged position without the adequate lumbar support, this stresses the spine and results in pains and an elevated likelihood of chronic pain and injury. Hence, wearable devices to enhance posture have become a crucial resource in reducing the health risks in the long term of sedentary living.

2.2.2 Behavioral Change and Health Benefits

Posture monitoring systems in the form of wearables do not only help in correcting posture but also make great motivators of behavior change. A survey conducted discovered that participants who wore a wearable posture monitor and received real-time feedback were better able to sustain better posture practices during the day. Wearable systems integration with smartphone applications creates a level of engagement, enabling users to monitor their posture change and get personalized advice.

Moreover, they can be of great health advantage. Indeed, a 2021 study by Smith et al. showed that participants who followed posture correction feedback demonstrated a 30 percent improvement in chronic back pain, and more energy and less muscle fatigue after four weeks of the program [11].

In addition, recent research revealed that incorporation of relaxation methods in wearable devices enhances user adherence even more. The more holistic way of improving physical health is to use devices that remind users of simple stretching exercises or mindfulness activities after correcting their improper posture. One such case is a wearable device proposed by Kato et al. (2020), which comes with posture correction and mindfulness training, allowing users to alleviate stress and prevent discomfort due to poor posture

2.3 Objectives and Key Insights of the System

2.3.1 Key Insights from Research

The combination of muscle strain, real-time posture, and AI-based feedback systems development is becoming one of the important insights in the creation of wearable posture systems. A study by Tanaka et al. (2021) highlighted the need to use IMU sensors with electromyography (EMG) sensors to ensure that muscle strain is fully detected. Combining this information with AI algorithms, wearable systems will not only be able to notify users about improper position but also quantify the amount of muscle strain, preventing injuries related to muscle stress [12].

Among the significant findings of the research is the necessity of customization of wearables posture systems. Since the body shape, sitting and muscle conditioning of each user is different, a universal approach might not work.

2.4 Security Issues

2.4.1 Data Privacy Concerns

Since wearable systems would be gathering sensitive health information, including posture patterns and physical stress, there is a big worry regarding privacy of this information. Wearables are usually sent to the cloud storage, which increases the chances of data breaches and unauthorized access. The paper by Kumar et al. (2021) addressed the dangers of exposing personal data with the help of wearable health devices. End-to-end encryption, which is a secure storage solution is necessary to protect this data against cyber attacks [13].

2.4.2 Cloud Security

Although cloud storage offers straightforward access to user data, it also has its vulnerability. The recent research by Patel et al. (2022) was devoted to the significance of cloud-based wearable security. The study emphasized that the risks of cloud storage can be addressed through decentralized storage and using sophisticated encryption methods, including end-to-end encryption. Moreover, the use of blockchain technology can provide integrity and transparency of data and preclude an unauthorized access [14].

2.4.3 User Authentication and Authorization

Since wearable devices are sensitive in nature, stringent user authentication measures should be put in place. Zhong et al. (2022) suggested applying multi-factor authentication (MFA) systems to wearable applications to make sure that only authorized users can access the data. They use both biometric authentication, passwords and authentication based on devices to enhance the safety of wearable devices and user privacy [15].

2.5 Development Environment/ Languages Used

2.5.1 Hardware Platforms

Wearable posture systems are usually implemented on several hardware platforms, such as the Arduino and Raspberry Pi. Real-time sensor data are processed on these platforms. A work by Zheng et al. (2023) revealed the capability of the Raspberry Pi to process intricate data of various sensors and deliver real-time feedback in posture monitoring devices [16].

2.5.2 Programming Languages for Embedded Systems

Languages such as C and C++ are usually used in the development of embedded systems. These are excellent languages to interact with low-level hardware and achieve performance optimization. Nevertheless, more advanced languages such as Python and Java are also becoming popular in developing mobile applications to communicate with wearables. These languages provide flexibility in terms of sensors and data processing and developing user-friendly interfaces [17].

Chapter 3

Requirement Specifications

3.1 Existing System

The existing posture-correcting wearable systems are mainly based on the inertial measurement units (IMUs) to record the posture adjustments and give feedback. These systems work based on the acceleration and gyroscopes to provide feedback that the spine or limbs of the user are not at an optimal alignment and a range of commercially available devices offer easy-to-understand feedback, including a vibration during poor posture. Nevertheless, although wearable posture technologies have become a subject of increased research and development, there is a frequent limitation on real-time adaptability and full posture correction in existing systems [18].

Most recent studies have suggested wearable devices to monitor the posture on a continuous basis on IMU data and wireless communication as a feedback that real-time monitoring is not restricted to the simplistic alert systems. For example, wearable self-care systems with back-mounted motion sensors have been proposed to wireless track prolonged sitting posture, demonstrating that continuous IMU-based tracking can inform users of their sitting behaviors and support interventions to improve postural habits [19]. A lot of commercial and early research prototypes of posture monitoring solutions do not have some of the more advanced capabilities required to provide more personalized feedback and multi-modal sensor fusion, like machine learning classification and long-term trend analysis.

3.1.1 Key Limitations

The key limitations of current systems lie in several areas. First, they generally rely on a single sensor type (primarily IMUs) and lack the integration of additional sensors such as pressure or flex sensors, which can enhance accuracy in detecting multi-segment body postures [20]. Second, many systems do not incorporate machine learning techniques to adapt feedback to individual users' posture habits, which limits their ability to provide personalized interventions over time [21]. Third, these solutions tend to fail to monitor the long-term trends of the posture and adjusting the feedback to the behavior of users, which largely diminishes their ability to be effective in preventing musculoskeletal disorders in users [22].

3.2 Proposed System

The proposed wearable posture correction system will overcome the shortcomings of the existing estimated technologies by including various kinds of sensors, real time feedback and developing personalized postural information that is reinforced with machine learning models. The IMUs will constitute this system and will interact with other sensors such as the pressure sensor, flex sensor etc to sense the entire skeletal orientation and the postural subtlety. To enable the in-depth analysis of the trends and mobile feedback provision, the data will be stored long-term in a cloud-based platform.

Parallel studies with devices that use machine learning classification models have shown that IMU-based monitoring can distinguish between posture categories with great accuracy, and it is possible to have more complex real-time feedback systems that would go beyond vibration alerts and allow more subtle posture correction. Furthermore, systematic reviews have shown that wearable devices designed for posture monitoring and correction can influence alignment and muscle activity, suggesting that combined sensor systems with feedback loops improve postural awareness and biomechanical outcomes when compared to passive monitoring alone.

3.2.1 Key Features of the Proposed System

The following features will be the key features of the proposed system:

- The system is able to integrate IMU, ecg sensor, and emg sensor to provide details about posture in multiple body parts. This makes it more accurate than single-sensor solutions, and is better at detecting subtle deviations in spinal alignment.

- Instant feedback will be provided as haptic cues (e.g. vibration) and visual feedback through connected mobile application at the time deviations of healthy posture thresholds are observed. Studies indicate that corrective behavior adoption is boosted among users when latency-free feedback is used instead of latent feedback .

- A specific mobile app will provide users with a visual representation of real-time posture data and trends, and a cloud connection will provide the ability to analyze long-term posture and offer specific recommendations.

- Posture patterns will be analyzed over time with machine learning models to adjust feedback thresholds and offer personalized corrective recommendations according to the habitual posture patterns of each user, enhancing the system.

3.3 Requirement Specifications

3.3.1 Functional Requirements

The system shall:

- Identify posture abnormalities in real time and provide support to the user.
- Install IMUs, pressure sensors, and flex sensors to measure posture in various parts of the body.
- Apply machine learning to determine posture and personalize the feedback with historical data.
- Offer a mobile posture visualization and trend analysis.
- Store and result longitudinal analytics and future insights of information in the cloud.
- Enable the users to customize feedback sensitivity and types of alerts.

3.3.2 Non-Functional Requirements

The system shall:

- Extra-low latency in real-time feedback.
- Have a minimum of 8 hours of reliable usage.
- Offer an intuitive and user-friendly interface.
- Ensure high scalability for cloud storage and data processing without performance loss.
- Secure user data through encryption during transmission and storage.

3.3.3 Hardware Requirements

The hardware components required include:

- IMUs for orientation and motion tracking.
- Pressure sensors for contact and load detection.
- EMG sensor for muscle stress detection.
- A micro-controller for processing.
- Rechargeable battery for extended use.

3.3.4 Software Requirements

Software components include:

- An interactive mobile app to visualize and provide feedback of posture.
- Data storage and data analytics services on a cloud-based model.
- Posture classification and personalization machine learning libraries.

3.4 Use Cases

3.4.1 Use Case 1: Real-Time Posture Feedback

Actors: User, Mobile App
Preconditions: The device is worn and connected.
Main Flow:

1. The system detects posture deviation (e.g., slouching).
2. Real-time feedback through vibration and app notification.

3. The user adjusts posture based on feedback.

Post-conditions: The user regains proper posture.

3.4.2 Use Case 2: Long-Term Posture Tracking

Actors: User, Mobile App

Preconditions: The system has been used over several days or weeks.

Main Flow:

1. The user accesses the mobile app to view past posture data.
2. The system visualizes trends and insights on posture improvement areas.

Post-conditions: The user is informed of long-term posture habits and progress.

Chapter 4

System Design

This chapter provides a detailed description of the design and architecture of the proposed wearable posture correction system. It covers the key components of the system, design constraints, the methodology used for development, and how these components interact to achieve the overall goal of the system.

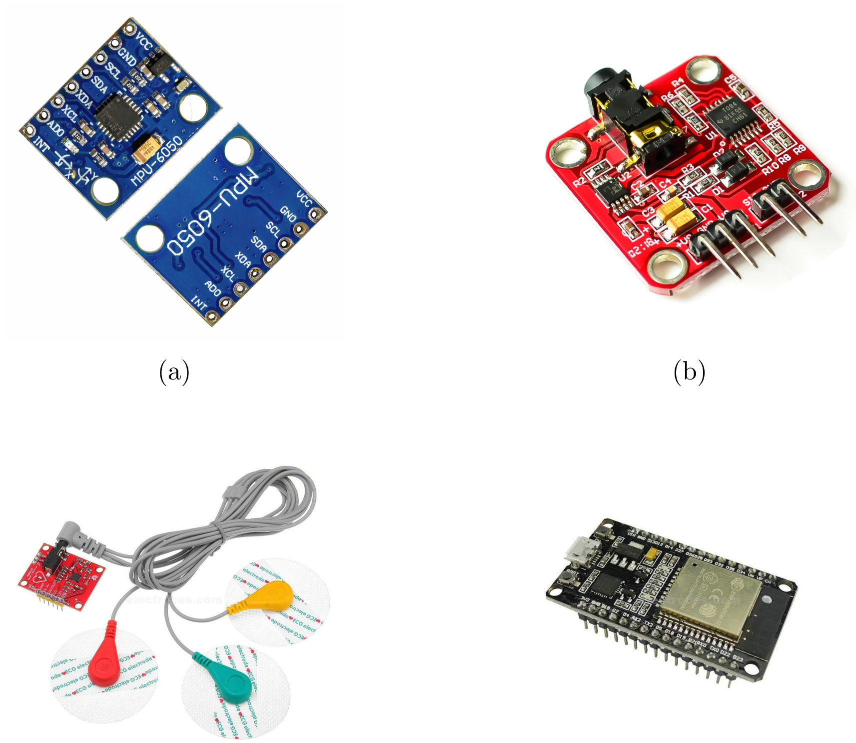
4.1 System Architecture

The system architecture defines the structure of the wearable posture correction system. It consists of both hardware and software, and gives a summary of how each interrelates with one another to fulfill the objectives of the system.

4.1.1 Hardware Components

The system consists of several hardware components integrated into a wearable device, including:

- Gyroscope (MPU-6050): This sensor is employed to monitor the orientation of the user's body and detect posture deviations.
- EMG Sensor: This sensor is used to measure muscle activity and detect muscle strain in real time. It helps the system identify stress on muscles caused by poor posture and trigger corrective feedback.
- ECG Sensor: ECG sensor is used to monitor heart activity and heart rate in real time. It helps detect physiological stress or fatigue related to poor posture and supports health monitoring in the system.
- Micro-controller (ESP-32): The ESP-32 operates with the data obtained on the sensors and provides feedback to the user.



(a) (b) (c) (d)

Figure 4.1: Hardware components (a) MPU-6050 (b) EMG sensor (c) ECG sensor (d) ESP-32

4.1.2 Software Components

The software components of the system include:

- Real-time Posture Detection Algorithms: It process sensor data in real time to detect deviations from ideal posture.
- Mobile App: A user-friendly app that displays real-time feedback, posture history, and analytics.
- Cloud Platform: Stores user data, provides long-term posture tracking, and enables data analysis.

The general architecture of the system is modular such that updates and integration with new technologies can be easily made.

4.2 Design Constraints

Design constraints are those constraints or limitations that must be put into consideration when developing the system. These limitations make the system viable, realistic and efficient.

4.2.1 Hardware Limitations

- The sensors should also be sensitive to capture minimal changes in the posture and at the same time be affordable.
- The wearable should be able to last longer (preferably over 8 hours) on one charge.
- The wearable should be light, comfortable so that the user has to wear it all day.

4.2.2 Software Constraints

- The system should be in a position to analyze sensor data in real-time to give instant feedback to users.
- The app should be supported by both Android and iOS users.

4.2.3 Cost Limitations

While the system uses advanced sensors, components must remain affordable for consumers, which limits the complexity of some hardware choices.

4.2.4 Environmental Constraints

The unit must be working in typical temperature and humidity conditions to make sure that the device is functional in different conditions (e.g. office, outdoors).

4.3 Design Methodology

The design approach used in coming up with the wearable posture correction system is an iterative approach which is user-centered. This approach will make the system satisfy the technical requirements and at the same time address the needs of the end users.

4.3.1 System-Level Design

The system-level design would start with the description of the main components (hardware and software) and their interactions. They have made the system flexible and scaled up by ensuring a modular architecture. The type of sensors selected and the mobile application platform (React Native), which would enable cross platforms compatibility, were chosen to provide the desired balance of accuracy and cost.

4.3.2 Development Process

Agile methodology had been used to develop the process of development and this implied that it could be prototyped and regular feedback could be given by the end user. Earlier iterations of the system were aimed at the combination of the hardware elements, and the subsequent work on the mobile application to monitor in real-time. A sequence of testing and refinement stages was performed, but they were founded on the user reaction and performance tests.

4.3.3 Development Models

System design was done in a step by step fashion where an individual component of the system was tested first and later integrated with the whole system. This allowed us to cope with such issues as sensor calibration, data synchronization and battery consumption.

4.4 High Level Design

The high-level design of the system illustrates the key components and their relationships.

4.4.1 System Block Diagram

The block diagram of the system is presented below in which the key system components are represented:

- Sensors: Gyroscope, EMG sensor, and ECG sensors collect data related to the user's posture.
- Micro-controller: Posture Correction The micro-controller interprets the information it gets off the sensors and identifies when posture correction is required.
- Feedback Mechanism: In the event of posture being detected as poor, the system provides feedback through haptic feedback mechanism or through a mobile app as a notification.
- Cloud Storage: Data is continuously uploaded to a cloud platform for long-term monitoring and analysis.

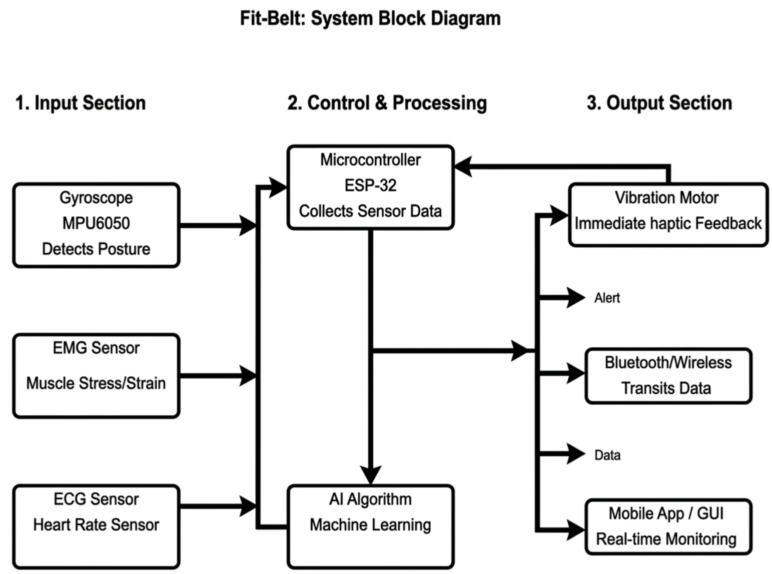


Figure 4.2: System block diagram of the proposed posture monitoring system

4.4.2 Data Flow Diagram

The data flow through the system involves the following steps:

1. **Posture Detection**: Sensors capture real-time data on the user's posture.

2. **EMG/ECG Sensors**: Detects stress/strain and measures heart rate in real-time.

3. **Processing**: The micro-controller processes the data, identifying deviations from the ideal posture.

4. **Feedback**: If a deviation is detected, feedback is provided to the user (via vibration or notification).

5. **Data Storage**: Data is sent to the cloud for storage and analysis.

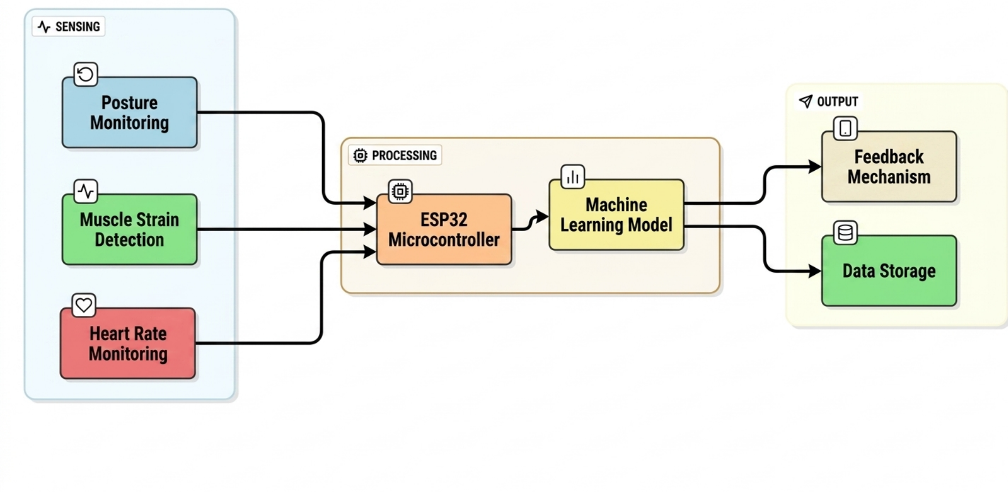


Figure 4.3: Data flow diagram of the proposed posture monitoring system

4.5 Low Level Design

Low-level design involves defining the detailed implementation of each system component. This includes:

- IMU sensors and other sensors will be designed to monitor the posture deviation with minimum power consumption.
- The on-board application actually runs algorithms to detect posture, which considers added factors like user activity, posture history, and sensor information.
- It creates a mobile application based on react native and can be deployed as a cross-platform application. It can communicate with the wearable device through Bluetooth and provide real-time feedback.

4.6 Database Design

Database design plays a vital role in terms of storage and administration of user information and monitoring long-term changes of the posture.

4.6.1 Database Schema

The database schema includes tables for storing:

- User Data: Information about users (e.g., name, device ID, posture history).
- Posture Data: Readings of the sensors on a daily posture.
- Feedback Data: Information about feedback sent to the user (e.g. time of feedback, type of feedback).

4.6.2 Data Flow and Storage

The information related to the wearable is uploaded to the cloud platform and processed and analyzed. Historical data on posture is archived to be used in trend analysis, and long-term tracking.

4.6.3 Security Measures

All data up in the cloud are encrypted such that they are confidential to the users. The data is only accessible by authorized devices and the user is in control of access to their information.

4.7 GUI Design

The graphical user interface design is concerned with creating user friendly interface of interaction with the system. The mobile app features:

- Displays live posture data and provides feedback on posture
- Progress Tracking: Displays trends over time, which can be used to monitor improvements.
- The user may customize the feedback to their preference.

4.7.1 User Flow

The user flow is designed to enable the user to easily configure the device, have a real time feedback and monitor their long term posture advancement.

4.8 External Interfaces

External interfaces define how the system communicates with other systems and components:

- The sensors and the wearable device use either I2C or SPI to communicate. The sensor data is transmitted to the micro-controller which interprets the information.
- The app works with the wearable device through Bluetooth Low Energy (BLE) with real-time posture measurements and transmitting a feedback to the user.
- The system is also connected with the cloud computing platforms (e.g. AWS, Google Cloud) to store the data and analyze it in time.

Chapter 5

System Implementation

Implementation is the process of transforming a conceptual system design into a functional and operational solution. It involves the realization of system specifications in the form of hardware integration, software development, algorithm deployment, and system testing. In this undertaking, the implementation stage entails the design of a wearable posture monitors and health tracker program based on various sensors, on-board processing and mobility application support.

5.1 System Architecture

The proposed system follows a modular architecture, which includes sensing, processing, communication, and feedback modules.

5.1.1 System Internal Components

The system is composed of the following primary components:

- IMU sensor (MPU-6050) of posture and orientation
- Muscle activity and strain monitor based on EMG sensor
- Heart rate and physiological stress sensor (ECG).
- ESP-32 micro-controller for processing
- AI-based posture classification module
- Wireless communication module (Bluetooth/Wi-Fi)
- Mobile application for visualization and monitoring
- Feedback unit (vibration/alerts)

Figure 5.1: System internal components

5.1.2 Functionality of Components

Each component performs a specific role within the system:

- Sensors capture real-time physiological and posture-related data.
- The ESP-32 micro-controller summarizes and filters all the incoming sensor data.
- The posture information is processed by the AI algorithm according to which it can be either right or wrong.
- The mobile application receives data sent by wireless communications.
- The mobile application provides posture, stress and activity indicators.

- The feedback module will notify the user when bad posture has been detected.

5.1.3 Communication Between Components

The system is a three-layered system:

1. Communication between sensors and controllers over I2C and analog signal.
2. Controller-to-mobile communication using Bluetooth/Wi-Fi protocols.
3. Controller-to-feedback communication through digital output signals.

5.2 Tools and Technology Used

To do it, both hardware and software technologies are used:

- Sensors: MPU-6050, EMG module, ECG module
- Micro-controller: ESP-32
- Programming platforms: Arduino IDE, Python
- Communication: Bluetooth and Wi-Fi
- Development tools: MATLAB for signal analysis
- Data visualization: Mobile GUI dashboard

5.3 Development Environment / Languages Used

The development environment includes both embedded and software programming platforms.

- Micro-controller/Sensor Interfacing C/C++ programs
- Python Data analysis and Ai model prototyping
- Arduino IDE to develop, and debug firmware
- Signal filtering and testing algorithms with MATLAB
- User interface development tools Mobile themselves

5.4 Processing Logic / Algorithms

It consists of a system with a structured processing pipeline:

1. Readings are obtained by sensor at IMU, EMG and ECG.
2. Signal sensor data is filtered and normalized.
3. Angles of the posture, muscle activity level, and heart rate patterns are computed.
4. Machine learning algorithms classify posture as correct or incorrect.
5. Alerts and vibration signals are triggered when poor posture is detected.
6. Data is stored and transmitted to the mobile application for monitoring.

5.5 Application Access Security

Security measures are implemented to ensure safe access and protect user health data.

5.5.1 Security Zones / Firewalls

Communication between devices and mobile applications is secured using controlled access protocols and protected networks.

5.5.2 Encryption

Wireless data transmission is encrypted to prevent unauthorized interception.

5.5.3 Authentication

User authentication is implemented through login credentials such as username and password.

5.5.4 Authorization

Different access levels are defined:

- User access for monitoring personal data
- Administrator access for system configuration

5.5.5 Auditing / Access Logging

Interactions with the system, login attempts, and data access events are logged down to be monitored and analyzed.

5.5.6 Safe Data Storage

The health information of the user is safely stored in the application environment and can guard against unauthorized users.

5.6 Database Security

Database protection measures are applied to maintain data integrity and confidentiality.

5.6.1 Remote Access Control

Only authorized applications and devices are allowed to access the database.

5.6.2 Authentication

The secured login systems are used with organized password guidelines and account validation.

5.6.3 Authorization

The access permission to read, edit or store data is made clear by key roles of the users.

5.6.4 Anonymous and Group Users

Personal posture and health data are only available to the authenticated users.

5.6.5 Auditing / Logging

System logs record:

- Data updates

- User access activities
- Communication events

5.6.6 Data Protection

Data storage is done in a secure manner to ensure that data is not leaked, corrupted, or tampered with.

Chapter 6

System Testing and Evaluation

System testing is done on the entire integrated Fit-Belt system to ensure that all the hardware and software work together as per the requirements. This stage will verify that posture and physiological sensors, wireless communication, and feedback generation, and mobile applications can work under real-life conditions. To reach the high quality engineering solution, it is not enough to develop a working prototype. Evaluation of system effectiveness, reliability, usability and performance should be systematic. Therefore, this project was evaluated using the quantitative and qualitative approaches to evaluate how far the system has gone in fulfilling its purpose.

The testing and evaluation process focused on several key aspects, including the functional correctness of the posture detection system, the reliability of sensor data acquisition, and the accuracy of posture classification. Additionally, the responsiveness of real-time feedback, the stability of wireless communication, and the usability of the mobile application were thoroughly assessed. The system's safety and security of physiological data were also evaluated to ensure privacy and protection. These evaluations were conducted not only in terms of absolute performance but also in comparison to existing posture monitoring systems and wearable solutions.

The system was evaluated not only in absolute performance terms but also in comparison with existing posture monitoring systems and wearable solutions.

6.1 System Testing Approach

There were several stages of testing to be fully validate the system:

- All the sensors and modules have been tested separately, such as IMU, EMG, ECG, ESP-32, vibration motor, and communication modules.

- Components were all integrated and interaction among sensors, microcontroller and mobile application were tested.
- The entire wearable system was put to test in the actual conditions of use.
- The system was put up on human subjects and tested with the application to test comfort and usability.

6.2 Graphical User Interface Testing

The mobile application was tested with the user interface to give visualization of the posture and physiological data. The aspects that were evaluated were:

- Posture movement in real-time.
- Muscle activity and heart rate can be visualized
- Alert notifications
- Inter-screen navigation.
- Sensor data synchronization.

To test the GUI, various screen sizes were used to check the readability and consistency. Results showed that users were able to interpret posture alerts and system information easily, indicating an effective interface design.

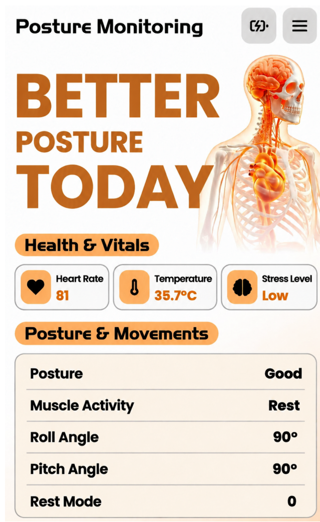
6.2.1 Testing GUI for Different Posture Positions

The GUI was tested for different posture in different conditions:

- **Case 1**

  In the GUI testing, the system recognizes good alignment of the spine when the posture angle is 90 degree with the user having his back straight and shoulders being relaxed and in line with the hips. The GUI gives real-time feedback which shows the right posture and that the appropriate corrective action is not required. The visual display on the screen also emphasizes the best posture positions, which makes users stay in the same position to enhance their spinal health.

(a)

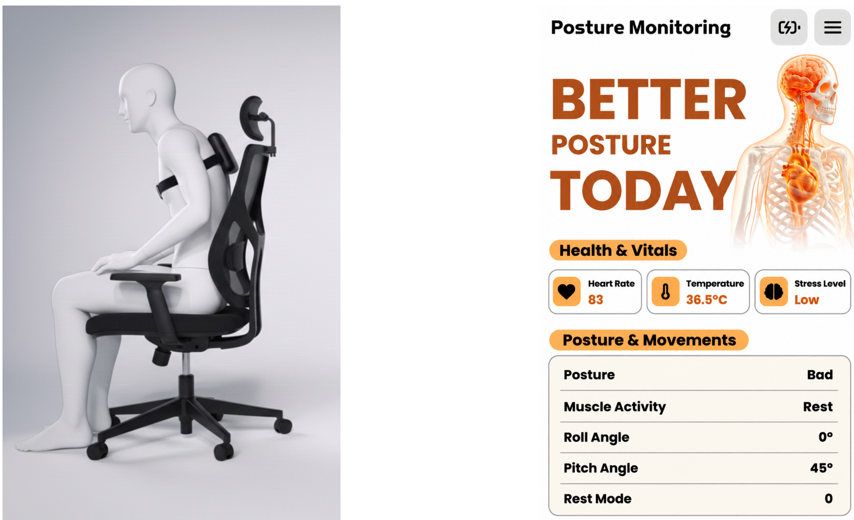


(b)

Figure 6.1: (a) Correct Posture Demonstration (b) GUI Result

- **Case 2**

  In the GUI testing, the system detects a slouched posture when the user's angle is at 45 degrees, with their back bent and shoulders rounded forward. The system provides real-time feedback, indicating that the posture is incorrect and corrective action is required. The visual display on the screen shows a warning, encouraging users to adjust their posture and return to an aligned position. The feedback also shows the points of concern like the curving of the spine and forward-leaning shoulders and users are expected to make the adjustments necessary to prevent any form of discomfort and long term spinal problems.

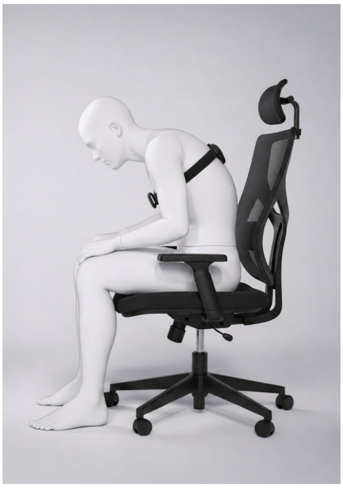


(a) (b)

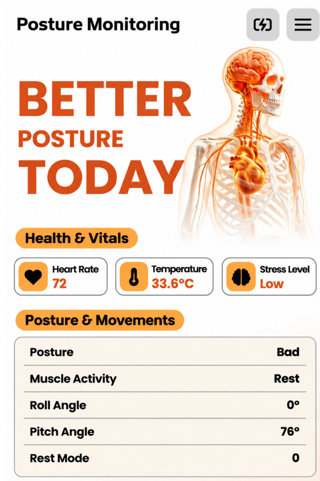
Figure 6.2: (a) Slouched Posture Demonstration (b) GUI Result

- **Case 3**

  The system identifies a slouched position at 75 degrees angle when the user is bent with the back being bent and shoulders rounded forwards in the GUI testing.



(a)

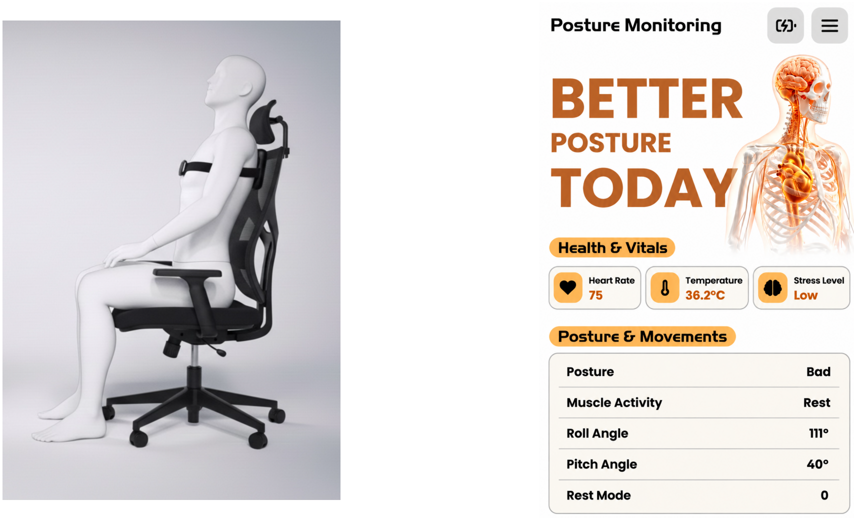


(b)

Figure 6.3: (a) Slouched Posture Demonstration (b) GUI Result

- **Case 4**

  During the GUI testing, the system recognizes a posture of bending backwards when the angle the user is at is 111 degrees with the back bent and shoulders drawn way back of the hips. The system offers real-time feedback, which indicates that the posture is wrong, and corrective measures are necessary. The visual display on the screen shows a warning, highlighting the exaggerated curve in the lower back and shoulders, encouraging users to adjust their position. The feedback helps users recognize the strain placed on their spine and urges them to return to a more neutral alignment to prevent discomfort and potential long-term spinal issues.

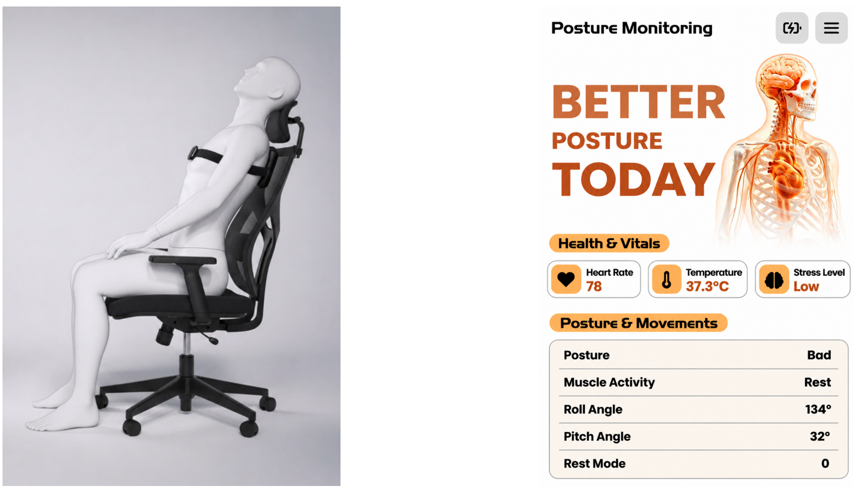


(a) (b)

Figure 6.4: (a) Backward Slouching Posture Demonstration (b) GUI Result

- **Case 5**

  In the GUI testing, the system identifies a bending more backward posture when the user maintains an angle of 134 degrees, with the back arched and the shoulders pulled far behind the hips.



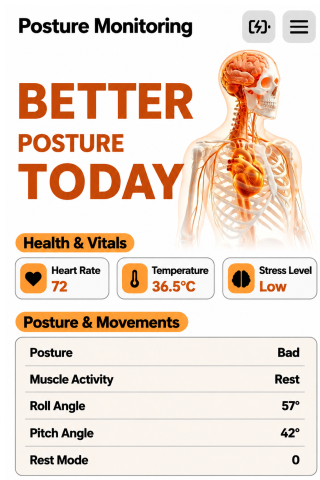
(a) (b)

Figure 6.5: (a) Backward Slouching Posture Demonstration (b) GUI Result

- **Case 6**

  In the GUI testing, the system identifies a bending right side posture when the user maintains a roll angle of 57 degrees and pitch angle 42 degree.

(a)



(b)

Figure 6.6: (a) Bending Right Side Posture Demonstration (b) GUI Result

6.3 Usability Testing

The usability testing was performed by letting the participants to wear the Fit-Belt system throughout their everyday routine and test such aspects as comfort, the ability to wear the device and take it off, the efficiency of the vibration feedback, the clarity of the mobile app notifications, and the ability of the user to understand the posture notifications. The system was reported to be user-friendly and not very disruptive to normal everyday activities and users felt that the system was user-friendly and non-invasive. A good response to the vibration feedback was generally evident giving clear signals to correct a posture. Moreover, users noted that the mobile application notifications were simple to comprehend and gave timely notifications. It was, however, observed that the long-term comfort would be enhanced by minimizing the complexities of wiring and decreasing the size of the hardware to make the device comfortable and wearable during the long term. These lessons will be used to inform future improvements to enhance user experience and device performance.

6.4 Software Performance Testing

Software performance testing was used to measure the data processing rate, time to execute algorithms, sensor data synchronization and real-time classification. The system proved to be capable of handling posture data with a minimal delay thus making sure that the alert was issued in real time. The reaction time was determined to be satisfactory with posture corrections being undertaken within a short period of time. Moreover, the system had steady sensor data synchronization, and therefore, posture monitoring was accurate and reliable. The posture deviation real-time classification was effective, and there was no apparent delay in the feedback provision. These performance results demonstrate the capability of the system to provide timely and effective corrective actions, enhancing user experience and constant monitoring. The next stage of work can be aimed at refining the algorithm to run it even faster and more accurately analyze the real-time data.

6.5 Compatibility Testing

The compatibility tests were conducted to ascertain the functionality of the system in different devices and environments. These tests involved testing the Bluetooth connectivity with a range of Android devices, testing the functionality of the system in various environmental conditions and testing the functionality of the system in various body shapes. The results showed a high degree of connectivity and stability, and confirmed that the system can be used in a number of conditions and with different users. Moreover, the system showed good performance despite harsh environmental conditions, including different temperatures and humidity. Bluetooth connection was good, even over long distance, to maintain continuous transmission of data. In general, the system was very flexible and strong and provided smooth operation in various situations.

6.6 Exception Handling

Exception testing was performed under abnormal scenarios such as sensor disconnection, Bluetooth communication failure, power interruptions, and incorrect sensor readings. The system maintained safe operation by restarting sensor acquisition, displaying alerts in the mobile app, and preventing false posture classification. Also, it provided integrity to data that were buffered when there was a connectivity problem and then continued normal operation once the problem was corrected. There was also real-time feedback to the system users to tell them of any interruption to reduce the chances of misinterpreted posture analysis. These error conditions were carefully taken care of by observing strict safety standards to safeguard the user and the device. In addition, the system was meant to automatically adapt to different power levels without affecting the performance.

6.7 Load Testing

Security test was done to ensure user physiological data is safely handled by assessing secure wireless communication, user authentication in the mobile application and safe data storage mechanisms. Encryption and authentication protocols were tested to maintain privacy of the user, and so, sensitive information was kept safe during the system usage. These security controls offer a solid framework on how user information can be securely protected without interfering with system integrity.

6.8 Security Testing

Security testing facilitated the handling of user physiological data safely through the assessment of various critical areas such as secure wireless communication, user authentication in the mobile application and safe data storage mechanisms. Also, encryption algorithms and authentication processes were properly tested to ensure the privacy of users so that sensitive data could be safely preserved during the process and would not be accessed by anyone.

6.9 Installation Testing

Installation testing: This was done to test the process of installation of the system like, connecting the sensors, coding the microcontroller, installation of the mobile application and connection of the Bluetooth. It was easy to install and install, requiring little technical expertise; it was simple and could be available to many users. It was installed in stages which was easy to install and guidelines were provided on what to do. Moreover, it was very simple to install and connect the mobile application, and thus, it was simple to communicate with the wearable device. Overall, it was a quick and efficient installation process, which also contributed to forming a positive user experience.

6.10 Evaluation Metrics

To evaluate the system performance, quantitative measures of evaluation were established and the primary parameters were the accuracy of the posture detection, the time taken to react to the posture deviation and generate feedback and the reliability of wireless transmissions and the battery performance of the system in a continuous monitoring. Moreover, the user satisfaction was measured through the feedback, whereas the system stability was measured by the number of interruptions, which guaranteed the overall system performance and stability in the real-life scenario.

6.11 Results and Analysis

The system could achieve real time posture and physiological tracking and sensor fusion improved the quality of posture detection and machine learning improved classification accuracy. Some of the key observations are the IMU sensor able to identify changes in spinal alignment, the EMG sensor able to identify the conditions of muscle strain and the ECG sensor able to monitor the real time heart activity. The ESP-32 microcontroller guaranteed rapid processing of data and wireless transmission, and the AI algorithm correctly recognized posture. Also, the mobile application enabled easy visualization of the outcomes and the feedback system was effective to inform users when there was a bad posture, which enabled them to take corrective measures.

6.12 Comparison with Existing Systems

The current posture monitoring devices are normally based on single sensors and do not offer much feedback. The proposed system enhances these existing solutions with the use of several sensors, which allows a more complete study of the posture and physiological health. It integrates AI-powered posture classification to precisely recognize and correct posture deviation in real-time. Besides, the system will provide mobile visualization that will enable users to monitor their posture patterns and physiological status in the long run. The individualized posture correction feature also makes the system more effective as it offers personalized feedback to each user and allows the system to be more dynamic and responsive to posture management.

6.13 Strengths of the Proposed System

The primary advantages of Fit-Belt system are the real-time posture detection and correction, the combination of IMU, EMG, and ECG sensors to monitor everything and the ability to access the data via a mobile application and easily. It is also marked by the benefit of AI based classification of posture, enabling posture deviations to be identified and corrected, and it has a low-cost, extensible system architecture, that can be made better in future and expanded to a broader application.

6.14 Limitations of the System

The prototype has a number of limitations present, such as having to calibrate the sensors to achieve better accuracy, the use of wired connections, which can be uncomfortable to wear, and the limited battery life when used continuously. Moreover, the size limitations of the prototype hardware also affect the portability of the prototype and the EMG signals can be affected by noise and motion artifacts. The technology also relies on wireless connectivity to monitor the application and this may restrict its efficiency to regions where the signal is weak. These constraints are some of the areas that can be better in future versions of the system.

6.15 Critical Evaluation

Fit-Belt system is an effective wearable technology in posture and health monitoring. It is able to integrate sensing and processing and feedback into a dynamic prototype. Commercial deployment however requires further advancements, like optimization of the hardware size and batteries, and improved AI models.

There is no ideal engineering system, and so does this project. This project was meant to develop a functional, scalable and research oriented system. The evaluation shows that the proposed system is effective in correcting postures in real time, physiological measures, and improving the awareness of the users regarding their posture behaviors. Future potential features include cloud based analytics, predictive posture controls and long term health monitoring.

Chapter 7

Conclusion

This project developed a smart wearable device based on AI, which consists of physiological and motion sensors, and which can monitor the posture and give the corrective feedback in real-time. The system would integrate different sensors such as IMUs, EMGs, heart rate sensors and ECGs in order to offer a total solution to correct posture and overall health monitoring. With these sensors, the device can detect posture deviations, monitor muscle fatigue, and detect levels of stress, rendering it more sophisticated than other posture devices that use a single sensor.One of the most remarkable outcomes of this project was the effective implementation of an embedded system based on ESP-32 microcontroller, allowing to obtain real-time data and process it and communicate it through Bluetooth with a mobile application. It is a low-power system, and hence can be used in wearable applications, or as a continuous system, without requiring high-end computing infrastructure. Besides, real-time posture classification with the use of AI showed that smart algorithms could provide wearable health devices with customized and adaptive feedback. Vibration notification and mobile alerts enable the user to adjust their posture immediately, which encourages good habits. The mobile application also assists the user to track posture and physiological data on a long-term basis, which promotes self-awareness and health-related awareness.Finally, the project demonstrates that posture correction in a wearable device with health monitoring is a feasible and effective solution. It helps expand the sphere of wearable health technology and gives an excellent basis to the future work on enhancing musculoskeletal health and well-being.

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Appendix A

User Manual

This user manual gives specifications on how to set up, operate, troubleshoot, and maintain the Fit-Belt: Smart Posture & Health Monitoring system. It aims to help users learn how to use the device in its best capacity to monitor their posture, measure physiological parameters, and enhance their health. The manual is designed in such a way that it is easy to use with all the features of the system operation being allocated their own sections.

1. System Setup

1.1 Unboxing and Initial Setup

After getting the Fit-Belt system, the package should consist of the following:

- Fit-Belt device.
- Type-C Charging cable.
- Quick Start Guide.
- Mobile App link (available for iOS and Android).

Follow these steps to set up the system:

1. **Charge the Device:** Use the USB cable that comes with the charger to connect the Fit-Belt to the charger. Always make sure that the device is charged completely prior to use.
2. **Install the Mobile App:** Get the mobile app in the App Store or Google Play Store. Use the instructions on-screen to create an account and to synchronize the device.

3. **Fit the Belt:** Place the Fit-Belt on your chest and make sure that the sensors are within the spine and the EMG pads are in position. Adjust the belt to be comfortable and touching the sensors.

1.2 Connecting the Device

1. Enable Bluetooth in your smartphone and make sure that the Fit-Belt is switched on.

2. Open the mobile app and select “Scan Device” from the menu.

3. Pair the device with your smartphone from the available Bluetooth devices list.

2. Operational Instructions

2.1 Using the Fit-Belt

The Fit-Belt is real-time monitoring and feedbacking the posture. The following is how to make it work:

1. **Posture Detection:** The machine constantly checks your posture alerting about the misalignment of your posture, i.e. the slouch or the forward-bend.

2. **Real-Time Feedback:** In case a posture deviation is monitored, the Fit-Belt gives immediate feedback, through vibration or mobile notification. Depending on the alert, change your posture.

3. **Physiological Monitoring:** The ECG and EMG sensors are used to measure the strain on the muscle and heart rate respectively. In case there is a lot of strain or stress, the device will notify you to adjust.

2.2 Mobile App Interface

The mobile application will provide real-time feedback and history. The main characteristics of the app are:

- **Dashboard:** Shows current posture status, muscle strain, and heart rate.
- **Progress Tracking:** View posture history and improvements over time.
- **Notifications:** Get notifications and physiological and posture change feedback.
- **Settings:** Customize sensitivity of feedback and type of alert.

3. Troubleshooting

3.1 Common Issues and Solutions

- **No Bluetooth Connection:** Ensure Bluetooth is enabled on your smartphone and the Fit-Belt is powered on. Restart both devices if the connection is not established.
- **Poor Posture Detection:** If posture deviations are not being detected, check the sensor alignment and make sure the device is worn properly around the waist.
- **Inaccurate Feedback:** If feedback is inaccurate, recalibrate the sensors by following the recalibration procedure in the app.

3.2 Device Reset

To reset the device:

1. Press and hold the power button for 10 seconds to turn off the device.
2. Power on the device again by holding the power button for 3 seconds.
3. Reconnect the device via the mobile app.

4. Safety Precautions

- **Proper Usage:** Do not wear the Fit-Belt too tightly. Ensure that the device is comfortably positioned to avoid discomfort or skin irritation.
- **Sensor Care:** Do not come into contact with moisture or high temperatures. Gently clean using soft cloth after use.
- **Battery Handling:** Do not leave the device on long periods of time. Only charge the device when the battery is low so as to extend its life.

5. Maintenance and Care

5.1 Cleaning the Device

Wipe the Fit-Belt with a wet cloth to eliminate dust and sweat. Do not immerse in water. In the case of the sensors, alcohol wipes should be used to disinfect them after use.

5.2 Updating Firmware

Regularly update the mobile application with firmware to make sure it has the latest version of software. Updates will improve the performance and will add new features. The Fit-Belt: Smart Posture & Health Monitoring system will help to enhance your posture and health in general. It can avoid the development of chronic musculoskeletal problems due to improper posture by giving instant feedback and offering individualized suggestions. This manual will make sure that users can easily set up, operate, and maintain the system to achieve the best outcome.

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