CENG424 Embedded Computer Systems
Spring 2024

Project Title: Keep Moving

Final Report

June 14, 2024

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Abstract

In modern sedentary lifestyles, the concept of ”good posture” has been scrutinized, with emerging perspectives suggesting that staticness rather than posture itself might be the primary cause of discomfort and pain. This project presents a posture monitoring system utilizing two MPU6050 sensors and an ESP32 microcontroller to detect both static postures and hunching. The system alerts the user through a vibration motor and a buzzer when prolonged staticness or hunching is detected. While traditional studies link bad posture directly to pain, our approach considers staticness as the main culprit, also recognizing the psychological and social impacts of posture, thus integrating a hunching detection mode. The system's functionality is validated through various experiments, proving its potential as a versatile tool for personal posture management.

1 Introduction

Back pain is ubiquitous and likely affects almost everyone across all cultures and ethnic groups at some point, with around 20 percent of people experiencing it annually, and up to 50 percent of these individuals experiencing it at least once a year Ehrlich (2003). Contrary to popular belief, there is no strong evidence that non-ideal posture directly leads to pain. Even if there is a relationship between pain and posture, it does not suggest a fundamental association. Pain can lead to poor posture; however, poor posture does not necessarily lead to pain Kripa and Kaur (2021).

Studies suggest that individuals with chronic back pain tend to adopt static sitting behaviors compared to their pain-free counterparts Bontrup et al. (2019). Thus, performing postural changes is a safer comfort strategy than maintaining an "ideal" posture all the time.

In light of these findings, the main purpose of this project is to encourage people to adopt healthier postural habits without imposing a strict posture. Our objective is to alert the user when a specific posture is held for a specified interval via haptic feedback and sound notification to remind them to stretch and change position with a wearable device. This approach is less invasive and more applicable to people with back pain, as they adapt specific pain-free positions based on their personal experiences Bontrup et al. (2019).

Although our main idea is staticness, we can not oversee the physiological and social effects of posture Nair et al. (2015). Thus, the device has a mobile app to change between staticness and hunching mode for the users that prefer sitting upright. Users also have the freedom to change the alert settings as to enable/disable vibration or sound alerts.

This paper presents the design and implementation of our posture correcting system, emphasizing the integration of movement and variability in posture management. By validating the system through various experiments, we demonstrate its effectiveness as a tool for improving posture-related health outcomes.

2 Literature Review

The field of posture monitoring and correction has seen significant advancements in recent years, with several products and research initiatives aimed at addressing the adverse effects of poor posture and prolonged staticness. This section reviews existing solutions and highlights the unique contributions of our project.

2.1 Existing Products and Research

One of the widely recognized products in the posture correction market is the Lumo Lift, a wearable device that provides real-time feedback on posture. It uses a small sensor placed on the upper body to detect slouching and vibrates to remind the user to straighten up Bodytech (2014). While effective in promoting better posture, Lumo Lift primarily focuses on upper body posture and does not address prolonged staticness.

Another notable product is the Upright Go, which attaches to the user's upper back and provides posture correction through vibration alerts. The Upright Go also offers an app for tracking posture habits over time Technologies (2016). Similar to Lumo Lift, its primary focus is on detecting and correcting slouching, with limited emphasis on dynamic movement or staticness.

In academic research, studies such as the one conducted by Kalantari et al. (2017) have explored the use of wearable sensors for posture monitoring. Their research demonstrated the effectiveness of accelerometer and gyroscope data in detecting poor posture Kalantari et al. (2017). However, the study primarily focused on posture detection rather than incorporating real-time feedback mechanisms or addressing staticness.

2.2 Unique Contributions of Our Project

Our project, "Keep Moving," builds upon these existing solutions by integrating multiple aspects of posture monitoring and feedback to provide a comprehensive solution. The unique contributions of our project include:

- **Dual-mode Detection:** Unlike existing products that primarily focus on slouching, our project offers two distinct modes: static detection and hunch detection. Static detection alerts users when they have maintained the same posture for too long, addressing the issue of prolonged staticness. Hunch detection, on the other hand, focuses on the psychological and social aspects of posture, providing alerts when the user adopts a hunched position.
- **Integration of Multiple Sensors:** Our design utilizes two MPU6050 sensors placed on the upper and lower back to provide a more comprehensive assessment of the user's posture. This dual-sensor approach allows for more accurate detection of both staticness and hunching.

- **Mobile App Connectivity:** The inclusion of Bluetooth connectivity and a mobile app enhances user interaction with the system. The app allows users to switch between detection modes and receive real-time feedback. This feature is particularly useful for promoting sustained ergonomic behavior.
- **Customizable Alerts:** Users can enable or disable vibration and buzzer alerts through the mobile app, providing flexibility in how they receive feedback. This customization helps users tailor the system to their preferences and needs.

By addressing both staticness and hunching, and offering a customizable and comprehensive solution, our project provides significant advancements over existing products. The integration of real-time feedback, dual-mode detection, and a user-friendly mobile app sets our project apart and offers a valuable tool for improving posture and reducing the risk of discomfort and pain associated with prolonged staticness.

3 Methodology

The methodology of this project involves both hardware and software components to effectively monitor and correct posture. Below is a detailed description of the components used, the system design, and the methods implemented for posture detection.

3.1 Components

The project hardware consists of the following components:

- ESP32 WROOM-32: A microcontroller with built-in Bluetooth and Wi-Fi capabilities, providing the necessary processing power and connectivity for the system.
- Two MPU6050 sensors: These are Inertial Measurement Units (IMUs) that provide six-axis motion tracking through a three-axis accelerometer and a three-axis gyroscope.
- Vibration Motor: Used to provide haptic feedback to the user for posture correction alerts.
- Buzzer: Provides auditory alerts to the user when poor posture is detected.
- LiPo Battery: A rechargeable battery that powers the ESP32 and sensors.
- Alkaline Batteries: Used to power the vibration motor and buzzer separately from the ESP32.

3.2 System Design

System architecture is shown in the figure below:

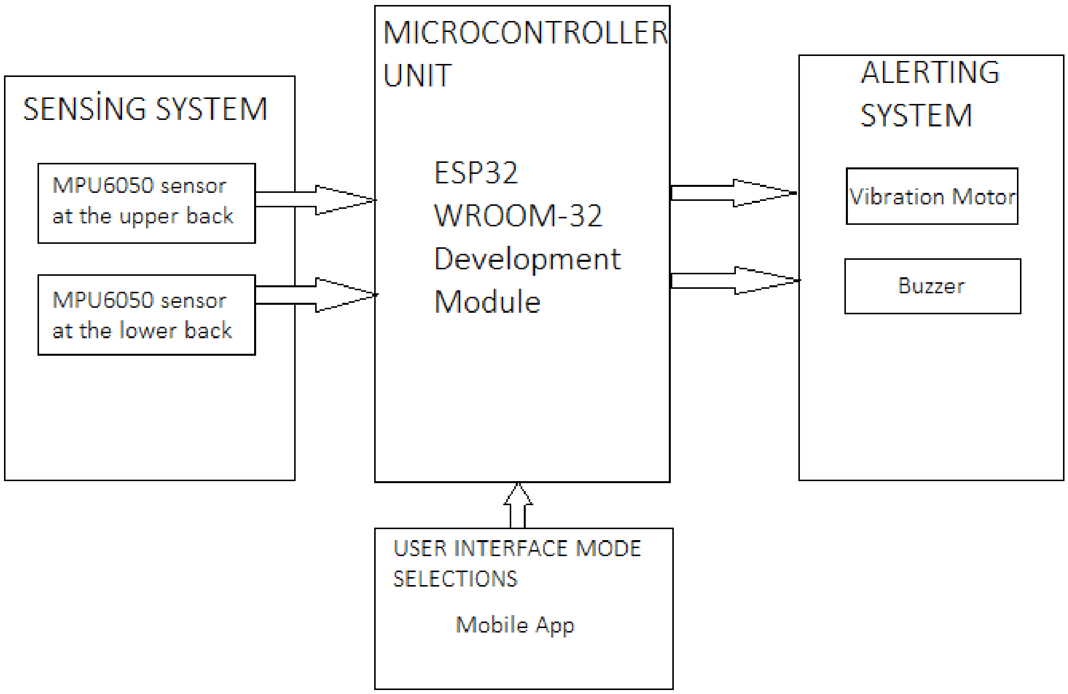

Figure 1: System Architecture

Physical product is shown in the figure below:

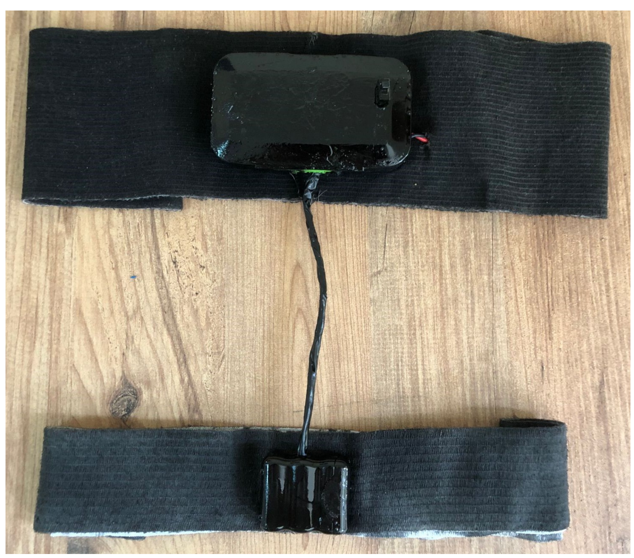

Figure 2: Physical Product

Circuit schematic of the system is shown in the figure below:

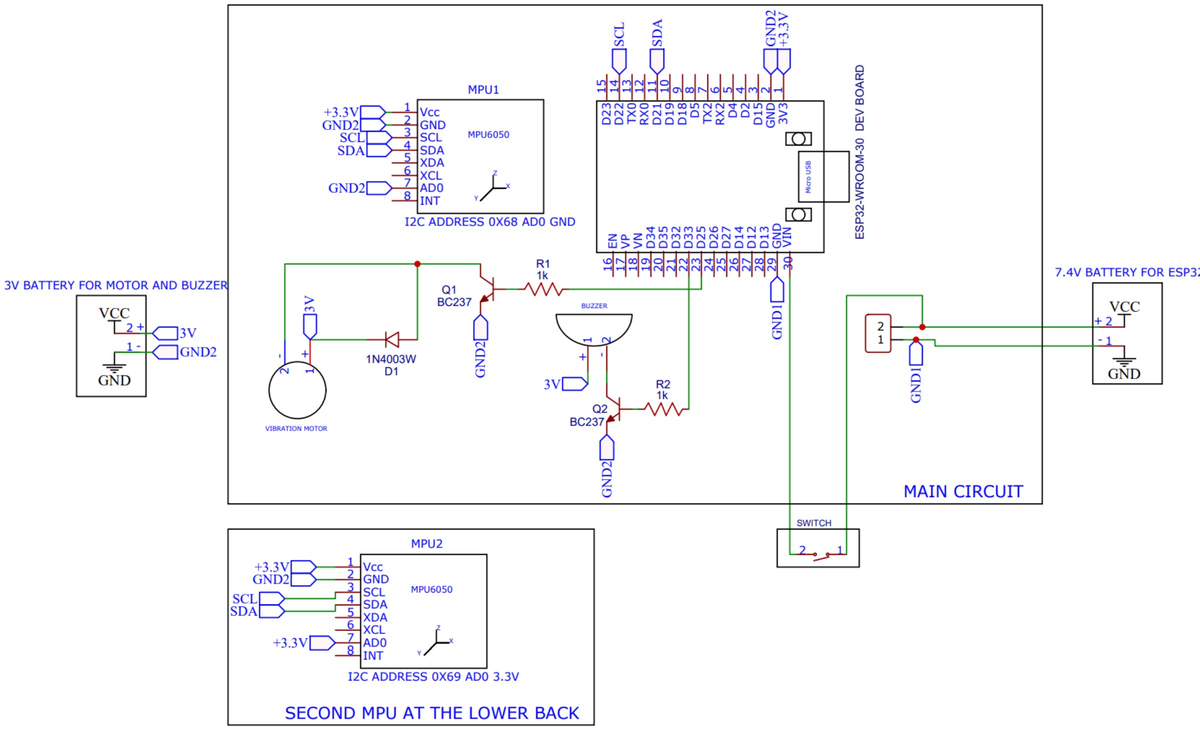

Figure 3: Circuit Schematic

3.3 Detection Methods

The posture monitoring system includes two primary detection modes: Static Detection Mode and Hunching Detection Mode.

3.3.1 Static Detection Mode

The static detection mode is designed to alert the user if they remain static (with minimal movement) for a specified amount of time. The steps involved in this method are as follows:

1. Processing the MPU6050 data to measure angles.
2. Comparing the previous angle values and current angle values over a specified amount of time.
3. Determining static posture based on a threshold value.

MPU6050 is an IMU device that stands for Inertial Measurement Unit. It is a six-axis motion tracking device that calculates three-axis accelerometer and three-axis gyroscope data.

Filtering Low-pass filtering is performed to get more refined data from the sensor.

Calibration Before using the data from MPU6050, the device is calibrated, meaning that we adjusted the measurements of the sensor such that they correspond with real physical values. The rotation rates must be zero when the device is stationary. To achieve that, the average of a large number of uncorrected measurement values is calculated when the sensor is stationary, and these offset values are subtracted from all future rotation rate values. The acceleration values in the directions of x, y, and z must follow Figure 4. To achieve that, we manually corrected the wrong values by adding or subtracting offsets.

Measuring Angles with MPU6050 We can obtain the angles by integrating rotation rates, which is gyroscope data.

$$Angle = \int_0^{k \cdot T_s} Rate\, dt \tag{1}$$

with k being iteration number and T_s being iteration length. Discretizing this integral we obtain:

$$Angle(k) = Angle(k-1) + Rate(k) \cdot T_s \tag{2}$$

The problem with this method is that it keeps adding previous errors of Rate(k) and causes the calculated angle to drift from the real value fast.

Another method uses the accelerometer values from MPU6050 to calculate angles. Accelerometer provides acceleration values along the x, y, and z axes.

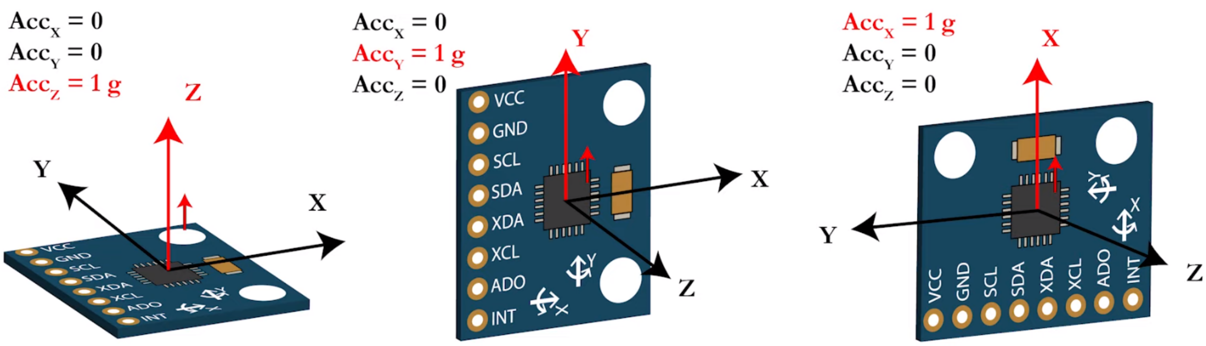

Figure 4: Acceleration values with x, y, and z directions being perpendicular to the ground

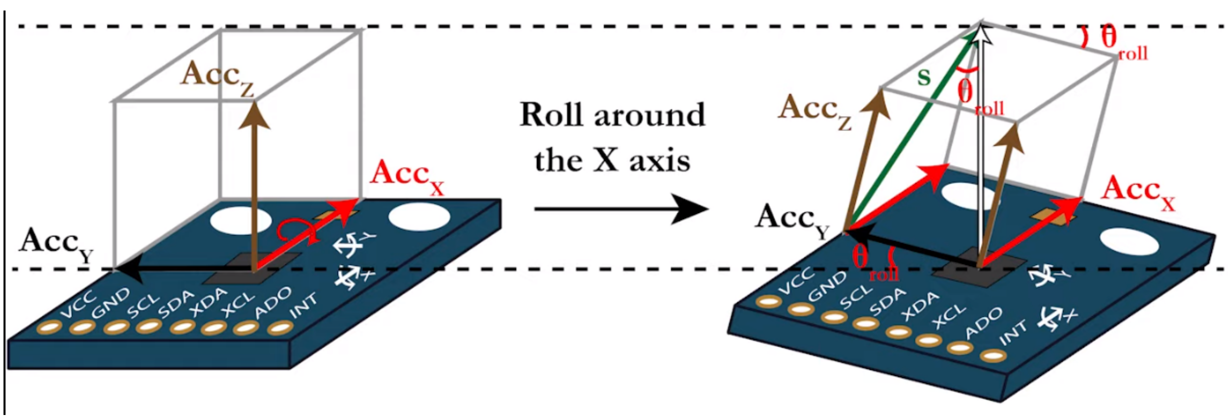

Figure 5: Angle and acceleration relationship

$$\tan\left(\theta_{\text{roll}}\right) = \frac{\text{Acc}_Y}{\text{Acc}_x} \tag{3}$$

Making use of trigonometry we calculate the roll angle:

$$\theta_{\text{roll}} = \arctan\left(\frac{\text{Acc}_Y}{\sqrt{\text{Acc}_x^2 + \text{Acc}_z^2}}\right) \tag{4}$$

For the pitch angle:

$$\tan\left(\theta_{\text{pitch}}\right) = \frac{-\text{Acc}_x}{\text{Acc}_z} \tag{5}$$

$$\theta_{\text{pitch}} = \arctan\left(\frac{-\text{Acc}_x}{\sqrt{\text{Acc}_x^2 + \text{Acc}_z^2}}\right) \tag{6}$$

The problem with this method is that it is greatly affected by vibrations.

A method is used that combines these two methods by a Kalman filter.

3.3.2 Hunching Detection Mode

The hunching detection mode is designed to alert the user if a hunching posture is detected. The steps involved in this method are as follows:

1. Processing the two MPU6050 data to measure angles, particularly the pitch angle.
2. Subtracting and taking the absolute of the the pitch angles of the two MPU6050 sensors placed on the upper and lower back.
3. Determining hunching posture if the comparison value is higher than the threshold value (e.g., more than 15 degrees).

The second sensor's pitch angle is used to ensure that the device does not detect leaning, but detects hunching. If only one sensor is used, device cannot distinguish between leaning and hunching.

The integration of these two detection modes provides a comprehensive posture monitoring system that addresses both static postures and dynamic postural changes such as hunching.

3.4 Mobile Application

- Developed using MIT App Inventor.
- Allows selection between 'Hunching' and 'Static Motion' modes.
- Provides personalized alerts based on selected mode.

Mobile app graphical user interface is shown in the figure below:

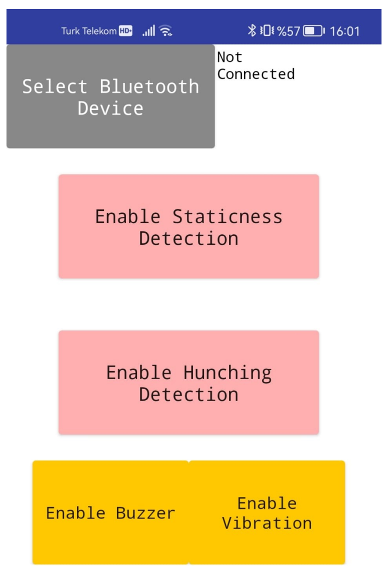

Figure 6: Mobile App GUI

4 Conclusion and Future Works

We started our project by obtaining readings from the MPU6050 sensor using ESP32 on Arduino IDE. Initially, the readings were insufficiently accurate. We applied offset calibration and filtering to optimize the data.

4.1 Calibration and Filtering

Offset calibration to correct inaccuracies. Low-pass and Kalman filters to reduce noise and enhance accuracy.

4.2 Thresholds and Mobile Application

Established thresholds by testing for static and hunching detection. Developed a mobile application to allow mode selection and provide alerts.

4.3 Future Improvements

Miniaturizing the device for user comfort. Improving detection accuracy by fine-tuning thresholds and exploring advanced filtering. Expanding the mobile app functionality to provide detailed posture data and insights.

- Miniaturizing the device for user comfort.
- Expanding the mobile app functionality to provide detailed posture data and insights.
- Reducing to only one battery and optimizing power consumption of the device by revising the code.
- Improving detection accuracy by fine-tuning thresholds and exploring advanced filtering.

By reducing the device's size and integrating it seamlessly with the mobile app, the posture correction device can become an effective tool for promoting healthier postural habits and make users more aware by obtaining long term data of their posture.

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