GymHive Tracker

ECE 445 Project Proposal

Team 28

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1. Introduction

1.1 Problem

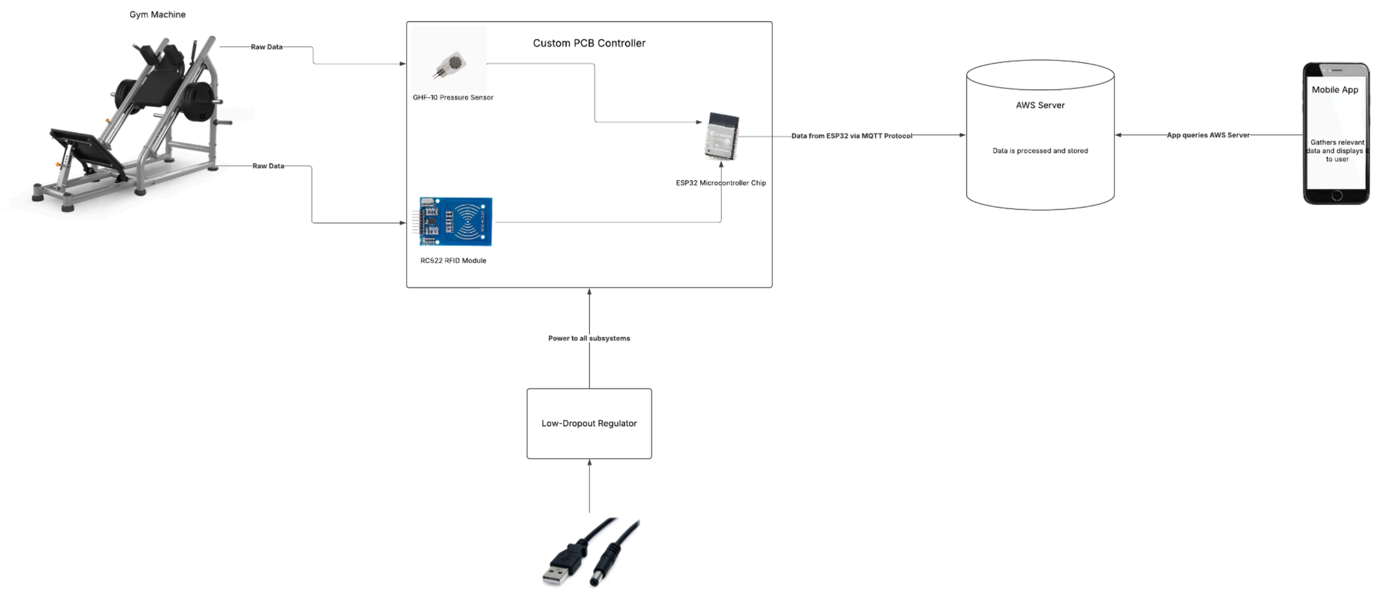
During peak gym times, equipment tends to get occupied quickly, which leads to long wait times and disrupted workout routines. Many gym-goers rely on consistent machines to track their progress weekly, but delays caused by occupied machines tend to force them to wait or alter their regimens. This inefficiency wastes time and reduces overall workout effectiveness for the athlete.

1.2 Solution

Our solution to this obstacle for gym-goers is the GymHive Tracker, a sensor-based system that monitors gym equipment utilization and provides individuals with real-time availability updates. We place our tracker at key contact points - such as pads, seats, or standing areas - and our system detects when a machine is occupied. To further optimize user satisfaction, we plan to implement a queue system where users can “check in” via their i-Card (simulating key fobs that are typically given by commercial gym establishments) on an RFID-enabled tag attached to each machine. Once checked in, users input their planned sets and reps, enabling the system to estimate wait times for those in line.

Rep and set tracking will be based on manual user input. Gym-goers will be able to input their desired sets and reps and modify it during their turns as they wish. To improve accuracy, our system will use data analysis from user inputs to learn and adjust estimated set durations over time (which tend to vary depending on the type of gym equipment). The system will notify the next gym-goer in the queue when the current user finishes their last set, minimizing wasted time. Each gym machine will have a dedicated PCB containing an ESP32 microcontroller chip that transmits data remotely to a central AWS server for processing. Users access this data through a mobile app by scanning their I-Card onto the machine's RFID reader, allowing for a seamless process. By integrating features such as real-time tracking, adaptive set duration estimates, and estimated wait times, the GymHive Tracker will enhance workout efficiency and promote optimized gym operations.

1.3 Visual Aid

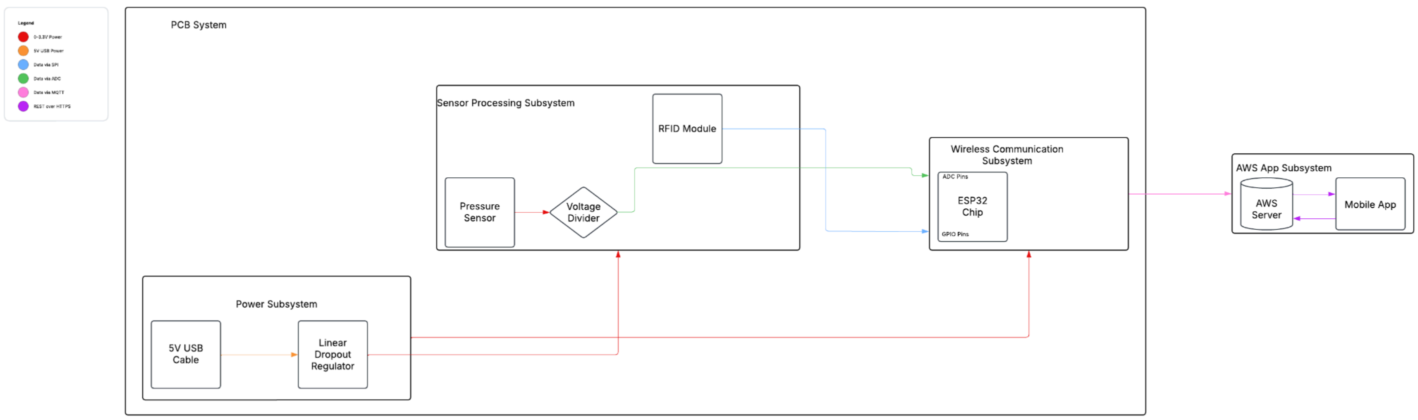


1.4 High-Level Requirements

1. **Real-Time Equipment Monitoring:** The system must accurately detect gym equipment occupancy with at least 95% accuracy (+/- 5 lbs threshold for acceptance), filtering out random weight fluctuations
2. **Efficient Data Transmission and Display:** The user must be able to transmit PII (personally identifiable information) via RFID within 1 second of scanning an i-Card. The microcontroller must process occupancy data and user check-ins within 3 seconds and transmit updated availability to the central AWS server ithin 1 second of an occupancy change.
3. **Queue Management and User Notifications:** The system must estimate wait times with a maximum error margin of 20 +/- 3% error margin (set and rep times tend to vary drastically across users for some equipment) by analyzing user-inputted reps and sets.

2. Design

2.1 Block Diagram



2.2 Subsystem Overview & Requirements

Pressure Sensing Module

- **Description:** This module detects whether the gym equipment is occupied. It used a pressure sensor to check when weight was applied to the machine.
- **Component:** GHF-10 [1]
- **Requirement:**
  - Must detect applied weight within ±5 lbs accuracy.
  - Must maintain 95% accuracy in distinguishing actual occupancy from fluctuations in sensor readings.

Microcontroller Chip

- **Description:** The Microcontroller Chip will be a part of the custom PCB we design, which will process the sensor data, handle communication via the RFID chip, and transmit data to an AWS server
- **Component:** ESP32 [4]
- **Requirement:**
  - The ESP32's ADC (Analog-to-Digital Converter) must read the signal and process occupancy data within 500 milliseconds to ensure real-time updates.

RFID Communication

- **Description:** This module allows for the ability of the user to use their smartphone to simply hover over the gym machine and be presented with the app to join and view the queue.
- **Component:** RC522 [3]
- **Requirement:**
    - Must recognize RFID tags within 1 second of the scan.

Mobile App

- **Description:** The app is designed to provide users with real-time equipment status and input/output functionality for them to “check in” to the machine.
- **Requirement:**
    - Display real-time occupancy updates.
    - Accurately track user check-ins and queue management.

Power Supply

- **Description:** This module powers the sensors and other hardware. From our datasheets, the MFRC522 RFID module has an operating voltage recommended at 3.3V. The ESP32 IC chip also runs at 3.3V. The GHF-10 pressure sensor does not have a specific operating voltage as it is designed to work with a voltage divider setup. We plan to run 5V continuous power via USB connection, which will require a USB-to-UART chip to interface with the ESP32 module. An LDO regulator will be needed to step down from 5V to 3.3V.
- **Component:** 5V USB cable and CP2102 USB-to-UART chip.
- **Requirement:**
    - All hardware must function correctly after 40 hours of operation in a simulated gym environment.

2.3 Tolerance Analysis

When utilizing a pressure sensing module embedded within common points of contact in a gym machine, it is critical to be able to determine whether the equipment is truly being occupied. It is therefore important to consider the accuracy and reliability of the GHF-10 to ensure that it does not pick up random weight fluctuations and throw a false positive. As listed in our high-level requirements, our accuracy threshold is +/- 5lbs, leaving us little room for error when detecting miscellaneous environmental factors or other movement patterns that may throw our sensor off.

In response to this, we analyze the feasibility of this component, by evaluating the sensor response to applied weight and movement fluctuations using mathematical analysis:

We model the force applied on the sensor as:

$$F_{total} = F_{user} + F_{machine} + F_{fluctuation}$$

where:

- F_{user} is the force exerted by the gym-goer,
- $F_{machine}$ accounts for the resting weight of the equipment/padding onto the sensor that may affect sensor readings,
- $F_{fluctuation}$ represents noise due to minor weight shifts, mechanical vibrations, and temporary pressure variations.

The pressure sensor must differentiate between actual occupancy and these fluctuations. The sensor outputs a voltage proportional to the applied force:

$$V_{out} = kF_{total}$$

where k is a sensitivity constant specific to the sensor.

Given the specifications of the **GHF-10 pressure sensor**, the output readings could fluctuate with repeatability and hysteresis of ±2%, which translates to a weight fluctuation threshold of approximately 2-3 lbs. So we need to ensure a ±5 lbs accuracy requirement so that $\left|F_{fluctuation}\right| < 5$

We implement signal filtering techniques such as:

- Low-pass filtering to smooth transient noise. [5]
- Kalman filtering to predict and correct erratic fluctuations. [7]

3. Ethics & Safety

- **User Data Privacy and Security**

  According to the IEEE Code of Ethics Section 1.1 [10], the intent of engineers should be to “hold paramount the safety, health, and welfare of the public”. By collecting and transmitting user data between the ESP32 microcontroller, AWS server, and mobile app, it is vital to encrypt this information using standard AES-256 encryption. Our goal will be to store as little personally identifiable information as needed, all of which will be securely encrypted.

- **Physical Safety of Equipment and Users**

  According to the ACM Code 1.2 [11], the goal of an engineer should be to “avoid harm… negative consequences, especially when those consequences are significant and unjust… include unjustified physical or mental injury, unjustified destruction…”. With this in mind, we understand how the custom PCB composed of pressure sensors and IMU modules must not only interfere with the intended use of the gym equipment but also not pose any risk to the gym-goers. We will ensure that each electrical component is securely enclosed to mitigate exposure to electrical or flammable hazards. Our PCB operates at a low voltage from 0 - 3.3V, which already reduces risks of any electric shock or fire hazards. This will severely minimize any risk of harm to either the gym goers themselves, the equipment, or the gym establishment.

- **Support each other in maintaining Ethical Standards**

  According to the IEEE Code of Ethics 7.8.III.10 [10], we must support our team members in following this code of ethics and reporting violations without fear of retaliation. This will ensure transparency and accountability. We will include this in our team contract to ensure we all agree on it.

4. References

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