Power Rack Manager

ECE 445 Project Proposal

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1. Introduction

1.1 Objective -

Power racks are a crucial component to a person's workout as you are able to partake in a multitude of weightlifting exercises. Every gym consists of usually multiple power racks that come equipped with a bench, a barbell and weights. Some of the exercises that you can accomplish with a power rack include squatting, benching, deadlifts, and cleans. Although these are the most common exercises that you are able to do utilizing a power rack, many more exist as well. Oftentimes when people show up at the gym, most, if not all, of the power racks are in use due to their highly versatile nature. People will then have to wait an unknown amount of time for the people that are using them to complete their exercises. People also often do not know whether or not there is a line to wait in to use a particular power rack because they are off doing other exercises. College students suffer through this problem the most as college gyms are often packed with people and lines form quickly to use the power racks. Although this problem has a significant effect on college students and their busy lives, it is not unique to them. Users of any gym have no doubt run into this issue at one time or another.

Our solution is a power rack managing device that consists of a system in which you are able to put your name in a queue to use a particular power rack. A LED display screen as well as a mobile application will display the current user of each power rack as well as the next three people in line waiting to use the power rack. It will also display a color to indicate whether the power rack is being used or not. A red color will indicate that the power rack is currently in use while a green color will indicate that no one is currently using the power rack. There will be a button attached to the power rack that a user will press when they begin using the power rack or when they have completed their exercise(s) on that particular power rack. When the button is pressed, signifying that a user has finished with a power rack, the queue will update on the LED screen as well as the app. An app notification will also be sent whenever the queue changes for the particular power rack that you are waiting for. There will also be an ultrasonic motion sensor that will sense whenever no one is using the power rack and if no one has been using it for two minutes, it will update the queue accordingly. This is to safeguard against people forgetting to press the button that signifies that they are no longer using the power rack.

1.2 Background -

For most weightlifters and people who exercise in general, power racks are critical for a successful workout. The versatility that they offer is unmatched by any other weightlifting equipment. Because power racks allow users to perform a wide variety of exercises, they are in extremely high demand. The issue is that gyms only have a limited number of power racks and during busier hours, lines form with people waiting to use the power racks. Sometimes, people have to wait for an absurd amount of time to be able to use a power rack. Personally, we have all had to wait 20 minutes or longer to be able to use a power rack. Waiting an extended period of time can disrupt the routine and rhythm of a person's workout and negatively affect the overall workout. Also, when longer lines form, confusion ensues regarding who is next in line to use a power rack. This occurs because rarely does someone sit around and wait to use a power rack. People usually tell the person(s) currently using the power rack that they are next in line before moving on to do another exercise while waiting their turn. This causes confusion on who is next in line. The Power Rack Manager can solve all of these issues by showing the queue for each power rack on a mobile application as well as an LED display. It can also allow you to add your name to the queue and signify when you are done with the power rack while updating the queue accordingly.

Our proposed solution to this problem is fairly different than the original proposed solution. The primary method of occupancy detection from the original solution is to use a large mat with load cells to determine if a power rack is in use. Our primary method of occupancy detection is simpler than this as we will just have a button that the user presses to signify that they are using the power rack as well as when they have finished. The original solution has an infrared sensor to detect movement near the power rack as a second method of occupancy detection. We will also be using a sensor, but we will be using an ultrasonic sensor instead of the originally proposed infrared sensor. The original solution also has a website as their interface to communicate whether a power rack is occupied or not. Our user interface is significantly more complex as we will have an LED display on the power racks that will show the name of the person who is currently using the power rack as well as the next three people in line to use it. We will also have a color indicating the usage status of the power rack where red means that the power rack is currently in use and green means that the rack is available. This data will also be displayed in the mobile application where people will be able to see how long the queues are as well as adding their name to a particular power rack queue. Notifications will also be sent via mobile application whenever their name moves up in the queue. The LED display will also be updated in accordance with the mobile application queue. The fifth and final difference between the original solution and our solution is that we designed our communication network differently. They have a more centralized, hierarchical structure where they have a master controller that governs sensor controllers and reports to a central server. Our network is simpler. Instead of waiting for the data coming from multiple sensor controllers in order to communicate data with the server via a master controller, we removed the master controller and will just use a single controller per rack to communicate individually with the server. This means that if one controller responsible for a rack goes down, it won't affect the functioning of all of the other controllers. It removes unnecessary levels of communication and adds robustness to the entire network by

1.3 Physical Design -

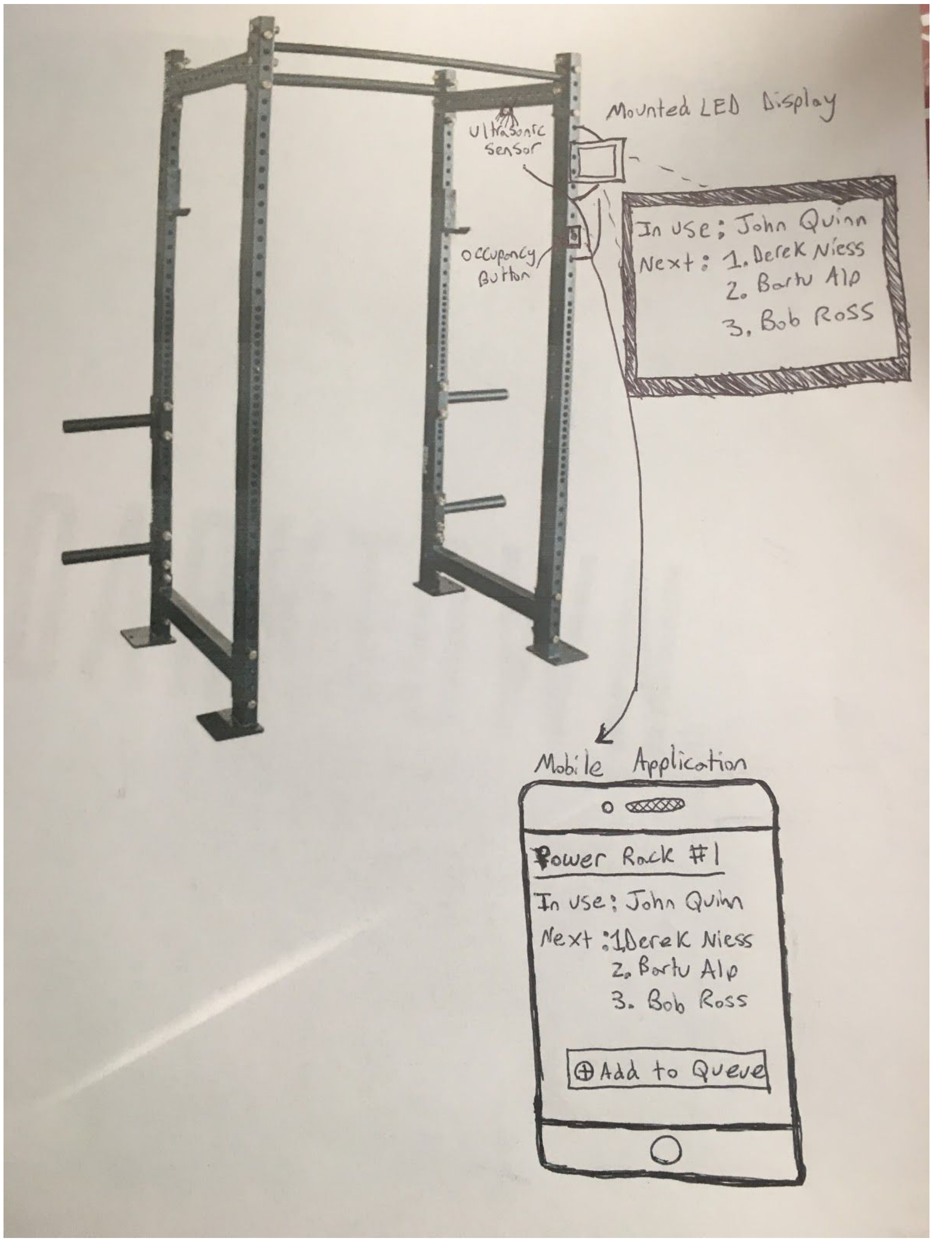

Fig 1. Physical Design of Power Rack Manager

1.4 High-level Requirements List -

- The mobile application must display the current queue list of every weight rack in the user's gym and the display must be refreshed within 5 seconds in the event of an update to any queue list.
- Once an occupied weight rack becomes vacant, the queue list of that weight rack should update accordingly (if there is a line), whether the occupancy button is

pressed or once the ultrasonic motion sensor detects no movement within a 2 minute interval.
- The mobile application must notify the users waiting in the queue within 15 seconds when their chosen rack becomes available for them.

2. Design

2.1 Block Diagram -

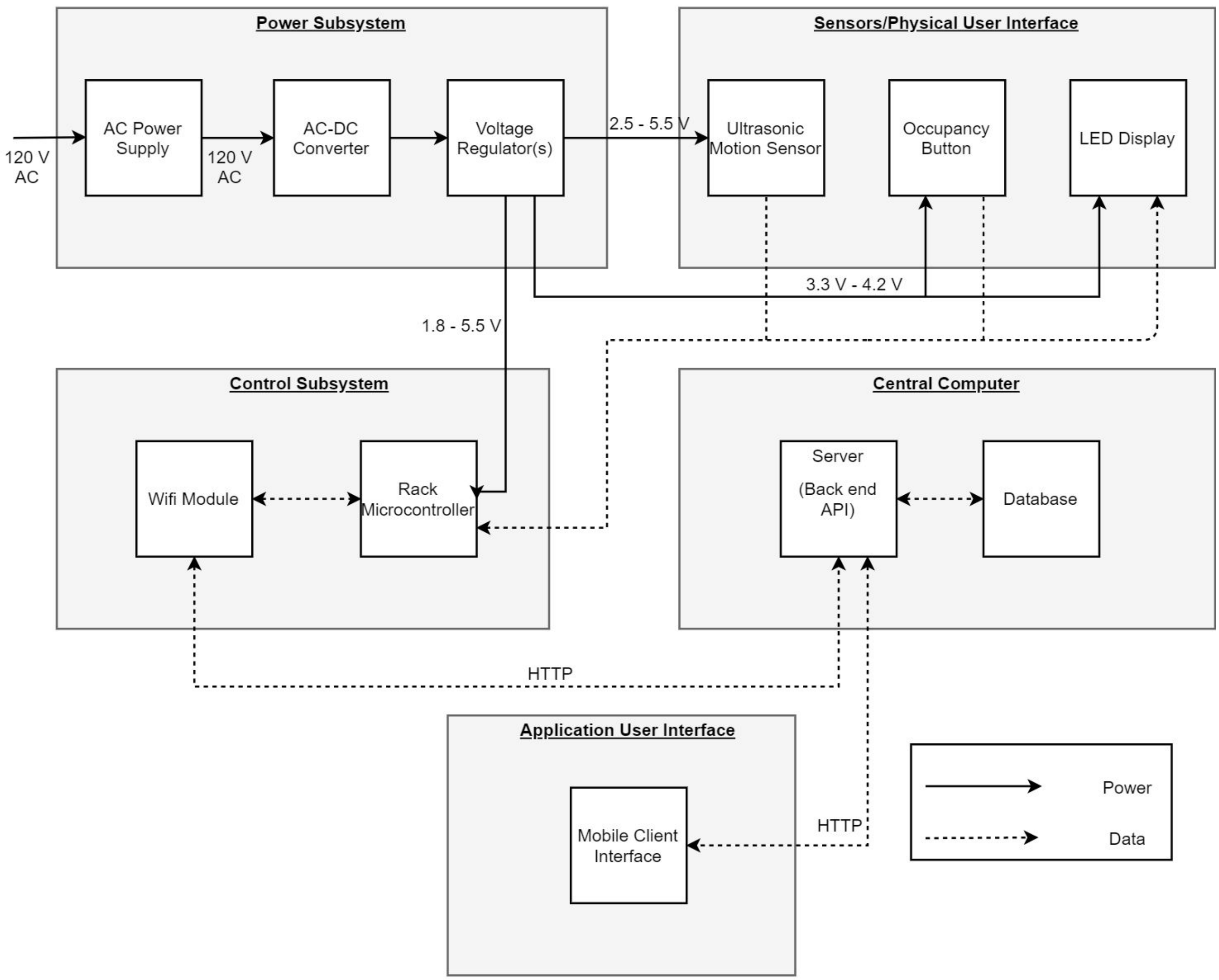

Fig 2. Power Rack Manager Block Diagram

Our design to optimize the use of power racks within the gyms consists of five different subsystems. The power subsystem takes in a 120 V AC and outputs to the components regulated DC voltage within the range of 1.8V - 5.5V. Its main aim is to power all the components of our design. The sensor interface will collect the user data and send it to the control subsystem for processing. The control subsystem will then output this processed data through the selected communication protocols to the central computer/server. Since we will also have a mobile app in our design, the server subsystem's responsibility will consist of sending the correct data to the mobile application. The application user interface will then display these data through the mobile application to our users.

2.2 Functional Overview -

2.2.1 Power Subsystem

The power subsystem will provide the necessary power to all components that require power in the Power Rack Manager. The power subsystem will take in the standard 120 V AC supply from any standard wall outlet and this voltage will be fed into an AC/DC power converter. This 120 V AC supply is readily accessible in any building so it is an easy choice for the power source of the Power Rack Manager. This does require, however, that each power rack is in close proximity to a standard wall outlet.

The AC/DC converter will then take this 120 V AC voltage and convert this to an appropriate DC voltage of approximately 5 V. The reason that we need the AC supply voltage converted to a DC voltage is because the components of the Power Rack Manager require an input voltage of DC. These components consist of multiple microcontrollers, an LED display, an ultrasonic motion sensor as well as an occupancy button. The AC/DC converter must also be able to supply an adequate DC current so that each component can be powered appropriately.

The DC voltage generated by the AC/DC converter will be then fed into a voltage regulator(s) so that the appropriate voltage levels to supply each component can be generated. The output(s) of the voltage regulator(s) will then be used to supply each component of the Power Rack Manager that requires certain DC voltage values. These voltage regulator(s) are critical in supplying the necessary DC voltage and current to each component of each power rack. Because each component requires slightly different operating voltages and draws various amounts of current, we anticipate having multiple voltage regulators for each power rack.

2.2.2 Sensors/Physical User Interface

The sensors/physical user interface system will be crucial in determining whether a power rack is in use as well as giving a physical display on each power rack of the name of the person using the power rack as well as the name of the people in the queue. This subsystem consists of an ultrasonic motion sensor, an LED display and an occupancy button.

The ultrasonic motion sensor is used to determine whether or not a person is currently using the power rack. It does this by detecting the distance between it and some object. When this detected distance changes, this means that there is movement within the power rack area and that someone is currently using the power rack. The ultrasonic sensor will send data to the microcontroller for processing and ultimately determining whether the power rack is in use or not. It will also be powered by a DC voltage and current that comes from the power system and more specifically a voltage regulator.

The LED display will show the name of who is currently using the power rack as well as the next three people who are in the queue. The LED will display the same data as the mobile application in this regard. It will be powered by the power subsystem and takes in a DC voltage supply. Data will be received from the microcontroller to determine the correct queue to display so that it is in sync with the mobile application. An LED display will be equipped on each power rack in a particular gym so that it can display the unique queue for each individual power rack. This LED display will be useful in that people who are physically at the gym can go up any power rack and see how many people are waiting to use a specific power rack without looking at their mobile device.

The last component of this system is the occupancy button. There will be a button on each power rack that people will press when they begin using a power rack or upon completion of their exercise(s) on that power rack. This button will work together with the ultrasonic sensor as sort of a two factor system to accurately determine whether a power rack is in use. If a user forgets to press the button or prematurely presses it, the ultrasonic sensor will be able to determine if someone is using the power rack. The occupancy button will send data to the microcontroller of the specific rack for processing. It will be also powered by a DC power supply from the power subsystem.

2.2.3 Control Subsystem

The purpose of the control subsystem is to ensure the execution of the following tasks:

1) take in raw sensor data, pre-process it to remove signal noise and classify the rack as occupied or unoccupied
2) deliver occupancy record updates to and retrieve user rack requests from the central server
3) cache the most recent snapshot of the rack's queue for displaying to the LED screen
4) in the event of a subsystem failure, refreshes the cache by making a request to the central server for the current queue of the rack.

To do these things the control subsystem will be composed of a microcontroller and wifi module.

The microcontroller will be responsible for scheduling and executing each of the above tasks. The MCU will follow the communication protocol followed by the chosen ultrasonic sensor to poll for changes in detected distance within its scope of sight. Given that the sensor is likely to exhibit signal noise--this is because it reports distance measurements in near continuous time and there is always some error for each measurement--a filter will be applied to smooth out measurements. These measurements will then be used to calculate the rate of change of the detected object, thus signifying whether the recent distances being measured is a human or an inanimate object such as a bench or the ground. The MCU will also store a cache of the running queue of the rack to eliminate the need to make a request to the server every time it wants to send queuing data to the LED display of that rack. The data in this cache will be periodically sent to the LED display via the chosen communicate protocol of the display.

The MCU will use a wifi module to communicate with the central server that manages the database. It will be responsible for maintaining the connection necessary for the following actions:

1) The MCU makes API update requests to the server to update the running queue recorded in the database when it is determined a user has ended or started his session, allowing the changes to be relayed to the application user interface.
2) The server sends updates to the MCU any time a user makes or cancels a reservation on the application user interface.
3) The MCU makes API get requests to the server in the event a system failure occurs and its cache is wiped.

2.2.4 Mobile Application UI/Central Computer

The end-user experience of this product, outside of the physical user interface, will be made through the use of a mobile application. As such, the components for this subsystem are all remote or software-based. They include a remote computer (we will be using an Amazon E2C instance), a database (we will be using a NoSQL DBMS), a server running the backend application (we will be using Apache), and the frontend client which will be the mobile application itself (as a SwiftUI).

The Amazon E2C instance is responsible for running the server and storing the database. The database will hold only the current queue status of each registered rack. The server will be running the API of our application, allowing the MCU and the frontend client to make queries and select modifications to the database. The frontend client is the mobile application that will display the current queues of each rack in the user's gym by sending queries to the server. It will also allow the user to add or remove his or her name to a specific queue by relaying the user request to the server for handling.

2.3 Block Requirements -

2.3.1 AC/DC Converter

Since the components of the survival wristband require a DC power supply, we will require an AC/DC converter to convert the standard wall outlet 120 V AC to a suitable DC level for operation. This AC/DC converter must be able to sustain an adequate amount of DC current to successfully operate all the required components as well. This generated DC voltage will then be connected to at least one voltage regulator in order to power the other subsystems.

Requirement 1: The AC/DC converter must be able to take the standard 120 V AC voltage supply and convert this to a range of 4.5 - 5.5 V DC for powering of the necessary components.
Requirement 2: The AC/DC converter must be able to sustain a maximum DC current of approximately 200 mA.
Requirement 3: The AC/DC converter needs to be compact in nature so that it is able to be mounted to the backside of each power rack as to maintain a neat and orderly area as to protect the equipment and prevent users from injury.
Requirement 4: The AC/DC converter must be able to operate below an operating temperature of under 45 ℃ to ensure safe thermal operation.

2.3.2 Voltage Regulators

Because many of the components of the Power Rack Manager require varying levels of DC voltage for optimal operation, at least one voltage regulator will be needed to reduce the DC voltage output from the AC/DC power converter. We foresee possibly needed additional voltage regulators as ideal operation voltage levels change for certain components. We will need one to supply DC power for the LED display and the occupancy button as these parts require an operating voltage that is less than the generated DC voltage of the AC/DC converter. However, the generated voltage from the AC/DC converter should be adequate for each rack microcontroller as well the ultrasonic motion sensor.

Requirement 1: For an input supply voltage of 4.5 V to 5.5 V, the voltage regulator needs to be able to supply an output voltage of 3.3 V - 4.2 V to successfully power the LED display and occupancy button.
Requirement 2: The voltage regulator must be able to operate under a temperature of 45 ℃ for safe thermal operation.

2.3.3 Ultrasonic Motion Sensor

A great deal of responsibility is placed on the ultrasonic motion sensor in order for the Power Rack Manager to operatore successfully. The ultrasonic motion sensor is responsible for detecting whether or not there is movement within the vicinity of each power rack in order to determine whether it is in use.

The ultrasonic motion sensor will be powered directly from the AC/DC converter as the voltage generated falls within the ideal operating range of the sensor. The Ultrasonic sensor will also transfer data to the microcontroller for further processing in determining whether a specific power rack is occupied. Because motion detection must be performed on a continuous basis, it must be able to transmit data to the rack microcontroller at a quick rate for processing. The ultrasonic motion sensor works by transmitting ultrasonic sound waves (high frequency) and, when this sound wave is reflected off of an object, a receiver determines if there are changes in the ultrasonic sounds waves in determining if there is motion. The ultrasonic sensor is able to detect the distance of an object and, when this distance changes (speed at which the ultrasonic sound wave is received), motion is detected and the appropriate signal is set which will be received by the microcontroller [3].

Requirement 1: The ultrasonic sensor must be able to transfer data at a rate of 2 seconds or under so that the microcontroller can process this data and determine if movement is detected.
Requirement 2: The ultrasonic sensor must be able to detect change in distances of a minimum of five inches in order to be able to successfully detect small motion.
Requirement 3: The ultrasonic sensor must be compact and able to be mounted at the top of the power rack so that it is able to be used properly to detect motion.
Requirement 4: The sensor must be able to operate at a temperature of under 45 °C for safe thermal operation.

2.3.4 Occupancy Button

The primary method of occupancy detection will be a button attached to each power rack that each user will press when they begin using a particular power rack and will also press when they have completed their usage of a power rack. This occupancy button will be powered from the power subsystem and, more specifically, from the voltage regulator as the occupancy button requires a DC supply voltage that is lower than the generator voltage from the AC/DC power converter. The occupancy button should also be in communication with the rack microcontroller to send data for processing. Data will be received by the microcontroller from the occupancy button to signify when the button is pressed in order to check whether or not the power rack is in use at that specific time. The occupancy button will work together with the ultrasonic motion sensor to accurately determine the usage of each power rack.

Requirement 1: The occupancy button must be able to be mounted on the power rack, easily accessible to everyone and easily pressed.

Requirement 2: The occupancy button must be able to transfer data at a rate of 2 seconds or under so that the microcontroller can process this data and determine if movement is detected.
Requirement 3: The sensor needs to operate at under 45 ℃ for safe thermal operation.

2.3.5 LED Display

The input of the LED display is the rack microcontroller. According to the signal it receives from the rack microcontroller, it will either output a green or a red color, green implying vacancy while red implying occupied. In addition to this, the LED display will also show its users, the number of people waiting in the queue for that specific rack so that people in the gym can plan ahead without the need of checking the app. Right below the number of people waiting for that specific rack, the LED display will also show the names of the top 3 people waiting in the queue. So, the LED display will have a color display, a number display and also provide the names of the top 3 people who are about to use the rack. The LED display gives a physical display of the queue as well as letting people know if the current power rack is in use. These will be mounted on each power rack and easily visible to the user. The LED display will be powered by the power subsystem from the voltage regulator as the DC voltage generated by the AC/DC generator is too high to adequately power the LED display. The LED display will have two way communication with the rack microcontroller so that the microcontroller is aware of what is being displayed and so the LED display is able to receive the correct data.

Requirement 1: The LED display must have a refresh rate of 3 seconds or quicker to update both the vacant/occupied display as well as updating the number and the names waiting in the queue.
Requirement 2: The LED display must be able to receive new data from the microcontroller in under 3 seconds so that it is able to have a refresh rate of three seconds.
Requirement 3: The LED display must operate at a temperature of under 45 ℃ for thermal safety.

2.3.6 Rack Microcontroller

The MCU will act as the primary source for handling communication. It will read raw sensor data from the button and ultrasonic sensor via manually assigned IO pins, write to the LED display via SPI, and make requests and receive responses from the remote server housed by a central computer. The microcontroller will also be powered from the power subsystem and the AC/DC converter as the voltage generated by the AC/DC converter is suitable for microcontroller operation.

Requirement 1: The microcontroller must be able to read and write via SPI at speeds more than 4.5Mbps.
Requirement 2: The microcontroller must be able to read data from the IO pins connected to the ultrasonic sensor and occupancy button.
Requirement 3: The microcontroller must operate at a temperature of under 45 ℃ in order to ensure thermal safety.

2.3.7 WiFi Module

In order for the MCU (microcontroller) to communicate with the mobile user application and server, it needs a wireless connection to transfer data through. The wifi module allows that very connection. As such, its function is entirely dependent on the function of the MCU and should be critiqued with respect to the MCU.

Requirement 1: When the MCU executes an API call, the server must receive the same HTTP request within 5 seconds.

2.3.8 Server/Database/Mobile App

The backend of our application is composed of a server and a database, where the server will be actively polling for incoming API requests and the database will house the current queue list of each registered power Rack. Once the server receives an API request, the function(s) associated with that request are executed, and the server will then either query or modify the database according to the request. The frontend is a mobile application generated using SwiftUI that will display the current data on the database for a particular gym.

Requirement 1: The server must be able to execute NoSQL statements that update or query the database with a successful return value.
Requirement 2: The mobile application must display the the updated queue list data of a weight rack within 10 seconds of it being updated in the database.

2.4 Risk Analysis -

The successful completion of the project depends upon three key factors; getting clean and accurate sensor data, processing this data through the communication protocols without any signal interference and providing real-time data to its users without any lags. All of these requirements carry a great amount of risk in which if one of them fails the whole design will provide wrong results to the user.

Getting clean and accurate sensor data is the first step in providing the user with the correct info. The risk associated with our sensor subsystem is due to the length constraint of each ultrasonic sensor. Every rack has a different height and since we are going to use the same sensor for every rack, we would need to choose a sensor that would be enough to cover the whole height of the rack. We place our sensors on top of the rack, so we chose a sensor that would provide accurate motion detection up to 6.5 meters which we believe is more than the height of nearly all the racks in the world. This way we can minimize the risk associated with the sensor subsystem.

Another risk associated with our product is to correctly send the signals from the sensors to the server. To accomplish this we will be using various communication protocols. An altered or lost signal jeopardizes the outcome, so we should choose the correct communication protocols, preventing any signal interference. This would minimize the risk factor of the control subsystem.

Finally, providing the user with real-time data is a very important requirement. We should achieve this without any lags since our product needs to be accurate within minutes if not seconds. To minimize the risk associated with the whole system, we need each of the subsystems to work properly and we need to implement a system that would constantly check if the user data is being refreshed within the predetermined rate of 10 seconds.

3. Ethics and Safety

Even though our project is not considered to be highly ethical at first glance, we believe that we are tackling a common problem for many sports enthusiasts. Our product intends to minimize the time lost in a gym as well as providing a fair distribution of equipment for all the gym members in the world. So, in other words, we are trying to create a product that would maximize the efficiency of our most important asset, time. We believe that a product/design that intends to create a fair environment for its users while minimizing the time they are losing is an ethical product.

To minimize the time lost for gym members, we are implementing an app that would notify its users about the vacancy of the racks in their gyms. This way users will be able to learn from the app whether or not there is an empty rack for them to workout. We will be totally honest and realistic while processing our sensor data to be as accurate as possible for each rack's vacancy. We believe this fulfills the 3rd clause of IEEE Code of Ethics which states "to be honest and realistic in stating claims or estimates based on available data" [1].

In the case when all the racks are occupied, we will have a queueing system that would allow the users to get in line for a specific rack. This way users won't lose time waiting for a rack to open up as they will be able to estimate when their rack will be vacant and schedule their time accordingly. In our experience, we have seen many individuals who waited for a rack to open up and when it was finally vacant, someone else just showed up and acted fast to steal their queue. Since our queuing system will provide an honest and fair way of equipment allocation, we fulfill the 8th clause of IEEE Code of Ethics which states "to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression” [1].

For a project like this, we, as a group, considered all the possible safety hazards that could happen in the desired setting and took the necessary precautions and measures to make our design/product as safe as possible. This approach aligns with the 1st clause of the IEEE Code of Ethics which states “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment” [1]. For safety precautions we focused on two possible scenarios; our sensors sending out wrong signals to the control subsystem and having liquid spill over our sensor and power subsystems.

In the first scenario when our ultrasonic sensor sends out the wrong signal, our product won’t be able to determine the vacancy of the rack properly, resulting in the lost time of our customers. For this case, we are considering the sensor itself to fully function. Since the sensor is fully working, the only scenario where it can send a wrong signal is if the height of the rack makes the ultrasonic sensor out of the rack’s reach. To tackle this possible safety hazard, we chose an ultrasonic sensor that can detect movement within 6.5 meters. We believe this is more than enough since there are not any gym racks that are higher than 6.5 meters.

For the second case, where a liquid spills over either the sensor or the power subsystem, there are possibilities of fire and getting shocked. Since gym is a place where the users sweat a lot while also consuming a lot of liquids whether it is water or something else, there is always the possibility of spillage. To minimize the possibility of this incident, the first thing we did was to place all the sensor subsystems on top of the rack. As we can see from the physical design drawing in figure 1, we placed the sensors away from most people’s reach. However, since our product needs to be connected to a power outlet providing 120V, we also needed some protection close to the ground. This is why all of our wires/cables going to the power outlet will be covered with “Medium Capacity Cord Covers” [2].

Looking at the previous group’s design, we also found a possible safety hazard. Since they implemented load cells below the rack, there was a possibility of the rack becoming unbalanced. Changing this with a button that is placed next to the sensor subsystem, cleared away the possibility of this incident.

We, as a team, believe that there is always room for improvement and will enhance our product/design by being open to any feedback and comment from our users. We believe this approach fulfills the 7th clause of the IEEE Code of Ethics which implies “to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others” [1].

Citations

[1] “IEEE Code of Ethics,” IEEE. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 03-Apr-2020].

[2] CableOrganizer.com, “Home,” Cord Cover Protection - Conceal Power & Data Cables. [Online]. Available: https://www.cableorganizer.com/cord-covers/. [Accessed: 04-Apr-2020].

[3] A. M. Zungeru, “Design and Development of an Ultrasonic Motion Detector,” International Journal of Security, Privacy and Trust Management, vol. 2, no. 1, pp. 1–13, 2013.