3. DESIGN APPROACH

The Workout Buddy is an automated fitness tracker that counts reps and sets using a motion sensor connected to free weight workout equipment. This free-range tracking system is compatible with any standard barbell and its respective barbell rack. The barbell may be fitted with the motion sensor unit that relays collected movement data to the microcontroller in the base system via Bluetooth. The base system then displays the current repetition and set count information on an organic light-emitting diode (OLED) screen for the user's convenience. The processed workout information is transmitted to the user's smartphone via near-field communication (NFC) once the workout is complete by simply touching the smartphone to the base system. The following sections describe the design options Bravo Builders considered, the design overview of The Workout Buddy, and the subsystems that compose The Workout Buddy.

3.1. Design Options

This section includes design variations and fitting options for The Workout Buddy. Several considerations were taken into account during the design process, including sensor placement, measurement data, and calculation methods. The following subsections cover some of the design options in more detail and clarify how the final design choices were selected.

3.1.1. Design Option 1

The Workout Buddy is an automated gym system using sensors that track the barbell and detect repetitions based on the user's movement. An OLED screen in the user's field of view provides constant feedback during their workout. This design ensures that the system is user-friendly and provides accurate data that is easy for the user to interpret. With this approach, the chosen sensor is located in the center of the bar so that it does not interfere with the user's hand placement during workouts. The location of the sensor system also provides protection for the sensor by placing it in a location that is not susceptible to high-risk impacts that may damage the sensor. The data provided from the sensor transmits the user's input via Bluetooth to the base system located on the rack. The base system then transmits the user's input via NFC to the smartphone.

Bravo Builders selected design option 1 because of the sensor placement on the barbell, the way the workout data is transmitted, and the location of the OLED screen. The sensor system location was a crucial factor in selecting design option 1 since it decided how the user's input data was collected. The Workout Buddy is split into two main systems including the sensor system and the base system. The sensor system and base system communicate with each other via Bluetooth, and the base system communicates with the user's smartphone via NFC. The OLED screen is placed in the base system located on the rack; this location prevents damage to the screen.

3.1.2. Design Option 2

The Workout Buddy is a workout enhancement that allows users to keep track of their barbell path metrics. The Workout Buddy consists of a display screen, two inertial measurement unit (IMU) sensors, a microcontroller, and a Bluetooth module. The OLED display screen stationed on the barbell displays reps and sets of the completed workout. The IMU sensors are placed bilaterally, with one sensor system located on each end of the barbell. This sensor placement provides ease of use for exercises in which the user may be in direct contact with the center of the barbell, such as for squats. The two IMU sensors communicate with each other via Bluetooth, transmitting data to one another, for an accurate display of information. Using NFC, the user can tap a smartphone to either sensor to transmit the data to the app.

Bravo Builders did not select design option 2 because of the sensor placement, the OLED screen location and the way user input is transmitted. The sensor system would be split in two with an IMU sensor located on each side of the barbell to triangulate user input. Bravo Builders decided against the two IMU sensors on the barbell because of the complexity of collecting user input and sending it to the user's smartphone. The data would then be sent to each IMU sensor via Bluetooth and the user would use NFC to send the workout data to a smartphone. The OLED screen for design option 2 would be located with the sensors on the bar, Bravo Builders decided against this option due to the risk of damaging the screen during a workout.

3.2. System Overview

The following subsections consist of The Workout Buddy's Level 0 and Level 1 prototype design plan and functionality.

3.2.1. Level 0

The Workout Buddy has two inputs and one output as shown in Figure 3-1. The physical design is broken down into two parts with each part receiving power. The sensor system has a rechargeable battery as the power input and user input as the data input. The output for the sensor system is the data input for the second system, the base system, which has two inputs, the sensor system output as well as power. The output for the base system is the workout data the user receives on their smartphone. These metrics include rep/set count and form quality.

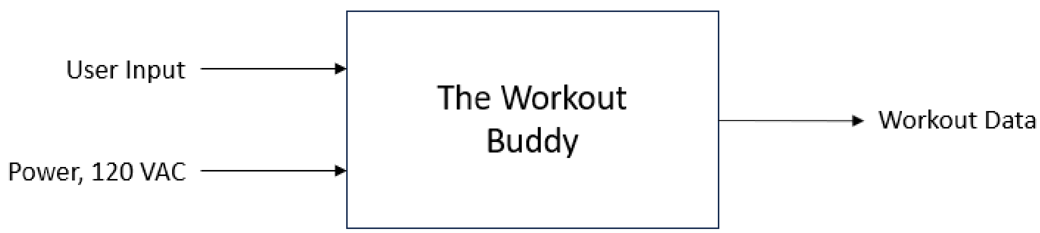

Figure 3-1. The Workout Buddy (Level 0)

The Workout Buddy has two inputs and one output. The functionality portrayed in Figure 3-1 is automated workout equipment that counts reps/sets for the user while also providing feedback about the user's form.

3.2.2. Level 1

Figure 3-2 shows a basic construction of The Workout Buddy, which is split into two main parts: the sensor system on the barbell, and the base system on the rack. The sensor system includes a six-axis IMU sensor with built-in Bluetooth powered by a rechargeable battery recharged by solar cells. The second part of The Workout Buddy is the base system that takes input data via Bluetooth from the sensor system. The base system includes a microcontroller with two inputs: the output data from the sensor system and the power. The output data is split into two parts, which include the rep/set data being displayed to the OLED screen and the notification that the user receives on their smartphone via NFC.

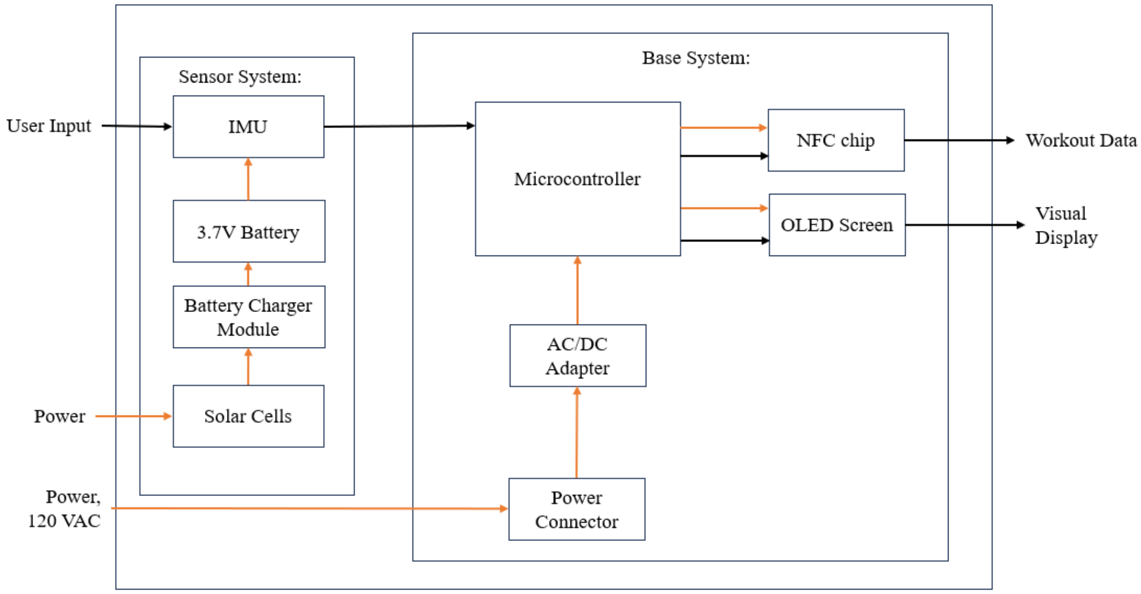

Figure 3-2. The Workout Buddy (Level 1)

Figure 3-2 displays how the subsystems of The Workout Buddy interact and how the sensor and base systems are attached to the barbell and rack. The wireless communication between The Workout Buddy and the user's smartphone is also illustrated.

3.2.3. Microcontroller

The Workout Buddy utilizes a microcontroller to receive and process the data collected by the IMU. The microcontroller communicates wirelessly with the IMU and the user's smartphone via a Bluetooth module and NFC chip, respectively. This device is powered by a wall outlet, so an AC-DC adapter is required for a proper power supply to the microcontroller.

Table 3-1: Microcontroller

Device	Voltage Output (V)	Current Output (A)	Clock Speed	Cost (USD)
Requirements	**≈ 5**	**≈ 2**	**≥ 1 GHz**	**≈ 50**
Raspberry Pi 4 [1]	5.1	2.5	1.5 (GHz)	61.99
Arduino Uno [2]	5	0.02 per pin	16 (MHz)	27.60
Arduino Mega 2560 Rev3 [3]	5	0.02 per pin	16 (MHz)	48.40

The Raspberry Pi 4 was chosen for The Workout Buddy's base system due to its superior processing power compared to the Arduino Uno and Mega microcontrollers, allowing for rapid analysis of input data received from the IMU sensor via the Raspberry Pi's built-in Bluetooth module.

Figure 3-3. Raspberry Pi 4 [1]

Figure 3-3 illustrates the microcontroller used by The Workout Buddy. This microcontroller will process data as needed during operation.

3.3. Subsystems

The prototype for The Workout Buddy includes five subsystems:

1. Sensor

   The Workout Buddy utilizes the Seeed Studio Sense inertial measurement unit (IMU) sensor package to obtain the barbell's acceleration and velocity to calculate repetitions and rate. The sensor uses inertial measurement tracking to acquire and transmit raw data for the base system. Also, The Workout Buddy displays bright-contrast graphics with an OLED display.

2. Power

   The Workout Buddy utilizes three methods for power distribution. The sensor system uses a 3.7-V battery as a primary power supply and a solar cell for backup charging; meanwhile, the microcontroller uses a standard 120 VAC connection for power.

3. Communication

   The Workout Buddy utilizes three methods of communication. Bluetooth is used to transmit data from the sensor system to the base system, NFC transmits data from the base system to the user's smartphone, and inter-integrated circuit (I2C) communication is employed to display data on an OLED screen.

4. Fitting Systems

   The fitting systems subsystem includes all sensor and wire placement and planning. Key foci of this subsystem include the protection of parts and the safety of the user. Another less consequential focus of this subsystem is overall appearance. This process includes cleaning up any stray wires and placing sensors and parts in locations that do not interfere with the user at any time.

5. Software Development

   The software development of The Workout Buddy focuses primarily on smartphone application development, but it encompasses all three discrete systems: the sensor system, the base system, and the user's smartphone. These three modules progressively collect, process, and share workout data with the user, eventually allowing said user to track their workout quality and progress.

3.3.1. Subsystem 1: Sensor

The Workout Buddy's objective is to gather essential barbell path metrics. The IMU sensor measures and tracks acceleration, velocity, repetition, and angular rate. The IMU sensor achieves path metrics using a gyroscope, an accelerometer, and a magnetometer. The hardware for the Workout Buddy operates at a viable voltage level and current consumption rate. The minimum number of motion tracking axes is six to achieve high performance rate and data transmissions. The dimensions of the IMU sensor are vital in the attachment to the barbell; the sensor must be compact and manageable for user's comfortability.

Table 3-2: IMU Sensor Comparison

IMU	Voltage (V)	Current Consumption (mA)	Motion Tracking Axes	Max. Dimensions (mm)	Cost (USD)
Requirements	**≤ 5**	**≤ 5**	**≥ 6**	**22 x 18**	**≤ 20**
Seeed Studio nRF52840 [4]	5	0.005	6	21 x 17.5	15.99
Adafruit BNO085 [5]	3.3	7.5	3	25.6 x 22.7 x 4.6	24.95
SparkFun ICM-20948 [6]	3.3	7.4	3	3 x 3 x 1	18.50
Bosch BNO055 [7]	3.6	13.7	9	36.7 x 14. 2	12.43

Based on Table 3-2, Bravo Builders selected the Seed Studio sensor for The Workout Buddy. This sensor was selected based on the factors of voltage, current consumption, motion tracking axes, dimensions, and cost. The Workout Buddy voltage and current meets the standard of the Seed Studio sensor. The sensor current consumption is lowest amongst fellow competitors. Although the voltage level is above the other options, the sensor meets the minimum number of axes needed for a better performance.

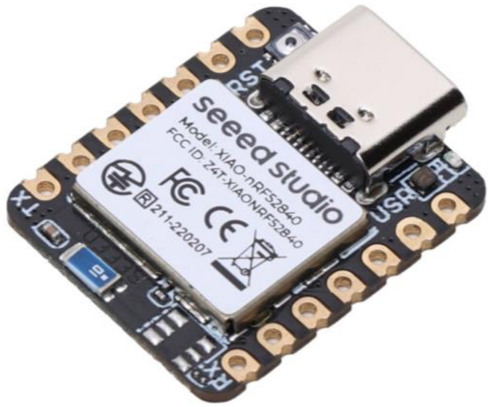

Figure 3-4. Seeed Studio nRF52840 [4]

The Workout Buddy utilizes an OLED display to present the user's mid-workout data. The OLED screen displays the reps at a fast-refreshing rate. This sensor is vital in user interface to ensure the user is consistently updated during their set.

Table 3-3: OLED Screen Display Comparison

Screen	Working Temperature	Resolution (Pixels)	Dimension (mm)	Display Colors	Power Consumption (Watts)	Cost (USD)
Requirements	**-20~50°C**	**128 x 64**	**28 x 11**	**White/Blue/ Yellow**	**≤ 1**	**≤ 10**
Hosyond OLED [8]	-20~60°C	128 x 64	27.3 x 10.9	White/Blue/ Yellow	0.06	2.99
HiLetgo [9]	-30~70°C	128 x 64	27.0 x 27.0 x 4.1	White/Blue/ Yellow	0.08	6.99
Uctronics [10]	-30~70°C	128 x 64	27.4 x 27.7	Yellow/Blue	0.04	6.99
GeekPi [11]	-30~70°C	128 x 64	28 x 27	Yellow/Blue	0.08	2.99

As stated in Table 3-3, the design team chose the Hosyond OLED screen. This decision is based on technical specifications of the OLED screen, such as size and cost. The Hosyond OLED maintains a reasonable price while having sufficient capabilities for the task at hand. The power consumption of the Hosyond OLED is less than one watt. The OLED maintains the needed display colors. The dimensions are consistent with the Workout Buddy's design for user's comfortability and visibility.

Figure 3-5. Hosyond OLED [8]

Figure 3-5 illustrates the Hosyond OLED that was chosen to display the rep count during the workout. This screen is placed in the user's field of view to reduce the user's risk of injury during the workout.

The Workout Buddy uses an NFC chip to transfer data between the microcontroller and the user's smartphone. The NFC chip is ideal for short range data transfer, ensuring that no data is being shared between devices unintentionally. When choosing an NFC chip to be used in the system, three main factors were taken into consideration. These factors include current draw, size, and cost of the device; comparisons are shown in Table 3-4.

Table 3-4: NFC Chip Comparison

Devices	Typical Current Draw (mA)	Size (mm)	Cost (USD)
Requirements	**< 5**	**≤ 0.5 x 4.0**	**≤ 2**
ST25DV02K-W2R8S3 [12]	4	0.154 x 3.9	0.96
RF430FRL152HCRGER [13]	1.4	4 x 4	4.04
M24LR64E-RDW6T/2 [14]	N/A	0.173 x 4.40	2.35

As stated in Table 3-4, The Workout Buddy utilizes the ST25DV02K-W2R8S3. This decision was made based on the small size and low cost of the ST25DV02K-W2R8S3. Although this device consumes more power than the other options it still fits the current draw requirement.

Figure 3-6. NFC Chip [12]

Figure 3-6 illustrates the NFC chip used to transfer data from The Workout Buddy to user device.

3.3.2. Subsystem 2: Power

The Workout Buddy uses a 3.7-V lithium battery and solar cell to power the sensor system. The base system is powered by a standard U.S. Type B outlet.

Table 3-5: Total System Power Draw

Device	Current Active Mode (A)	Current Stand By (µA)	Quality	Time (H)
Seeed Studio (XIAO nRF52840) [4]	0.2	5	1	1
Raspberry Pi 4 [1]	3	N/A	1	1

Based on Table 3-5, The Workout Buddy uses a Seeed Studio IMU sensor and a Raspberry Pi 4 to operate. The sensor requires 0.4A and 2V to operate correctly. The sensor also requires a battery that can handle 5uA when operating in standby mode. Table 3-6 lists the minimum requirements needed to fully operate the sensor system of The Workout Buddy.

Table 3-6: Sensor System Battery Comparison

Device	Output Voltage (V)	Output Current (A)	Rechargeable	Cost (USD)
Requirements	**≥ 2**	**≥ 0.4**	**Yes**	**≤ 10**
PRT-13851 [15]	3.7	0.4	Yes	5.50
Fraternize [16]	3.7-4.2	5.2	Yes	19.98
Adafruit [17]	3.7	6.6	No	27.99
PRT – 13852 [18]	3.7	0.04	Yes	4.95

Based on Table 3-6, the PRT-13851 battery was chosen to charge and implement the sensor properly. This battery was chosen due to its low cost of $5.50, and it provides adequate voltage to power the IMU sensor chosen in Table 3-2. The PRT-13851 is rechargeable, which was an important requirement in selecting a battery.

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Figure 3-7. 3.7V Lithium Battery [15]

Figure 3-7 is a picture of the battery that Bravo Builders selected as the sensor system power supply.

Bravo Builders chose to have solar cells to recharge the battery due to it always being able to supply power continually. The chosen requirements for selecting the solar cell were four factors including output voltage, output current, size, and cost. The Workout Buddy sensor system requires a solar cell that outputs enough voltage to power the battery charger module which in turn recharges the battery. Bravo Builders also wanted to make sure that the solar cell would be small enough so that it would fit on a standard 1-inch barbell.

Table 3-7: Solar Cell Comparison

Devices	Output voltage (V)	Output Current (mA)	Size (mm x mm)	Cost (USD)
Requirements	**2**	**≈ 100**	**Small as possible**	**≤ 15**
Sunymia Solar Cell [19]	2	160	50 x 50	15.50
Epoxy Solar Cell [20]	5	60	66 x 38	15.99
Aoshike Solar Cell [21]	5	60	53 x 30	15.99

Based on Table 3-7 Bravo Builders went with the Sunymia Solar Cell. The solar cell was chosen due to its small size since the sensor system is in the center of a barbell. Output current is a key factor when selecting a solar cell which is why Bravo Builders went with the solar cell that has the highest output current. Bravo Builders chose to have a solar cell to recharge the battery due to gyms always having artificial light in the facilities.

Figure 3-8. Sunymia Solar Cells [19]

Figure 3-8 illustrates the solar cells that passively recharge the battery selected from Table 3-7.

To charge the battery properly Bravo Builders elected to use a battery charger module. This device ensures that the battery does not overcharge or destroy the battery. Bravo Builders was looking for a battery charging module that charges the battery with a charging current greater than or equal to one amp but also had a cut-off voltage of 3.7-V. These requirements ensure that the battery is not pulling in too much current from the solar panel.

Table 3-8: Battery Charging Module Comparison

Devices	Charging Current (A)	Cut-Off Voltage (V)	Cost (USD)
Requirements	**≥ 1**	**≥ 3.7**	**< 10.00**
Hiletgo [22]	1	4.2	7.79
TP5100 [23]	2	N/A	8.89
TP4056 [24]	2	4.2	8.99

Based on Table 3-8, the Hiletgo was selected due to its small charging current and cut-off voltage that ensures that the battery fully charges. Due to the charging module being connected to the solar cell and the battery Bravo Builders had to ensure that it can safely charge the battery reducing the risk of damaging the battery. Cost is also a key factor in selecting the charging module which is why Bravo Builders selected the cheapest option.

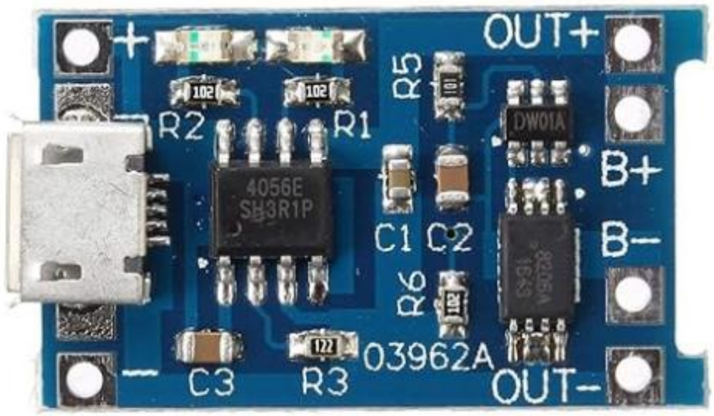

Figure 3-9: Hiletgo Battery Charging Module [22]

To safely power the Raspberry Pi 4 an AC-DC converter is required. The converter allows the base system to properly utilize power from a wall outlet without frying the Raspberry Pi 4. The chosen requirements for selecting the AC-DC converter were four factors including output voltage, output current, power output, and cost.

Table 3-9: AC-DC Converter Comparison

Device	Output current (A)	Output Voltage (V)	Power Output (W)	Cost (USD)
Requirements	**≥ 3**	**5**	**15**	**≤ 15**
Irm 15-5 [25]	3	5	15	11
Irm 60-12 [26]	5	12	60	18.55
Irm 15-15 [27]	1	15	15	10.57

Based on Table 3-9, Bravo Builder selected the Irm 15-5. The Irm 15-5 was chosen due to its output current, output voltage, and power output meeting the requirements selected. Cost is also a key factor in selecting the AC-DC converter, which is why Bravo Builders selected the cheapest option. This AC-DC converter allows the base system to safely power the Raspberry Pi 4 and the OLED screen.

Figure 3-10: Irm 15-5 AC-DC Converter [25]

Figure 3-10 illustrates the AC-DC converter that allows The Workout Buddy to use the Raspberry Pi 4 safely.

3.3.3. Subsystem 3: Communication

The Workout Buddy utilizes three forms of communication with two being wireless and one being wired communication. The two forms of wireless communication that The Workout Buddy uses are Bluetooth and NFC. Bluetooth transmits data from the sensor system to the base system, as seen in Figure 3-11. The second form of wireless communication, NFC, transmits the user's input from the base system to the user's smartphone. The wired communication that The Workout Buddy utilizes is I2C communication, which displays the rep/sets completed on an OLED screen.

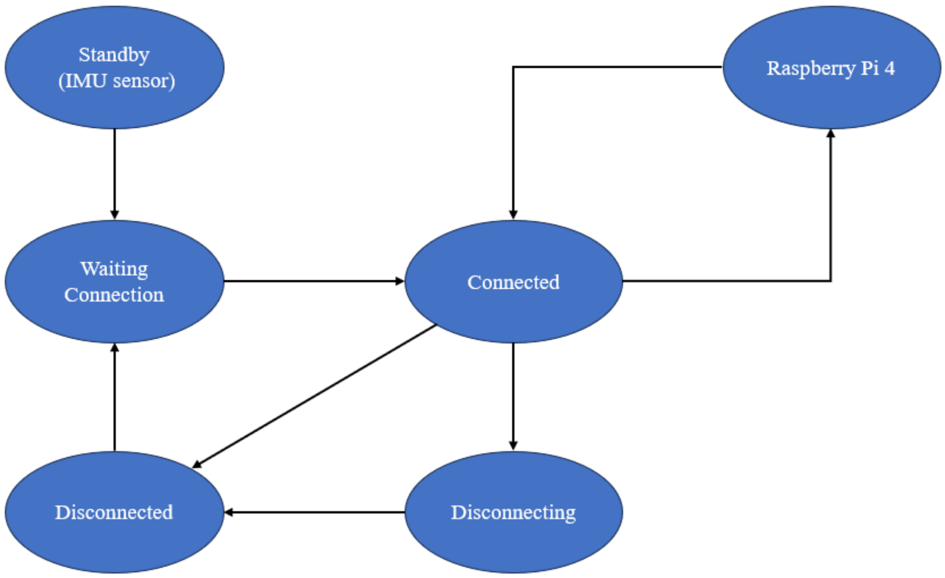

Figure 3-11. Bluetooth Pairing Diagram

Figure 3-11 shows a Bluetooth pairing diagram that The Workout Buddy is using to pair the sensor system and the base system together. The sensor and base systems begin in standby mode, awaiting a connection between the two. The two systems then connect; additionally, Figure 3-11 shows the process during disconnection and reconnection.

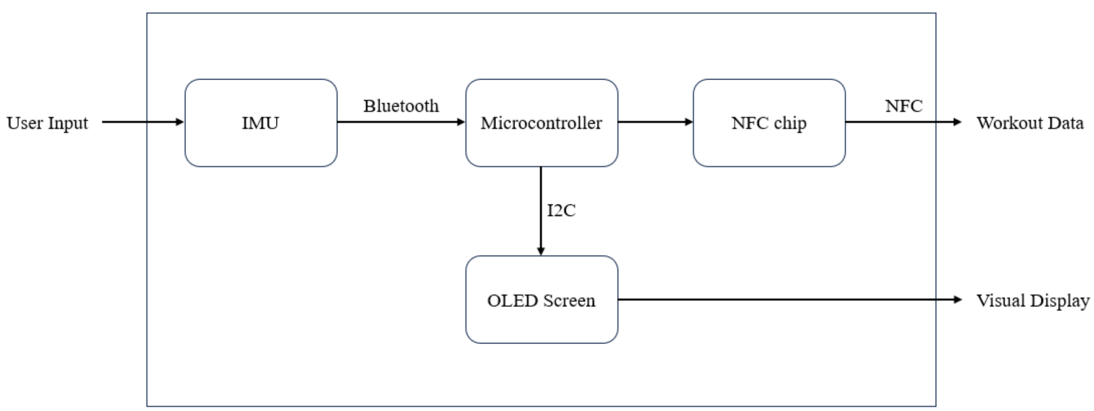

Figure 3-12. The Workout Buddy Communication Diagram

The diagram in Figure 3-12 shows the path of the data provided by the user's input. The IMU sensor transmits data to the microcontroller via Bluetooth while the microcontroller transmits data to the user's smartphone via NFC. The rep/set count is also streamlined to an OLED screen for user visualization.

3.3.4. Subsystem 4: Fitting Systems

Components of The Workout Buddy are fitted onto already existing equipment such as the barbell and rack. This system's components are required to handle stress and pressure due to the environment. To ensure the protection of these components, the Raspberry Pi 4, OLED screen, and AC-DC converter are housed in a 3D-printed enclosure. Bravo Builders decided on 3D-printed housing because of the ability to custom design the housing so that it fits the needs of the system. Table 3-10 lists options for filament materials and their properties.

Table 3-10: Filament Property Comparison

Filament	Tensile Strength (MPa)	Bending Strength (MPa)	Impact Strength (KJ/m^2)	Cost (USD)
Requirements	**≥ 30**	**≥ 50**	**≥ 5**	**≤ 0.60/ounce**
Overture PETG [28]	31.9 ± 1.1	53.7 ± 2.4	5.1 ± 0.3	0.54/ounce
eSUN ePLA [29]	61.34	100.27	6.3	0.65/ounce
Polymaker PA6 Nylon [30]	84.5	4431	16.5	1.70/ounce

As shown in Table 3-10, the Overture PETG (polyethylene terephthalate glycol) filament fits requirements as far as cost and strength capabilities. The stress resistance is lower than the other options, but still more than sufficient for use in The Workout Buddy. The Workout Buddy utilizes this filament to construct the housing for circuit components that require protection. Since 3D printing is used to construct the enclosures, there is a full range of customization when housing the parts. This casing provides the ability to effectively cover the parts in a way that does not interfere with the user.

Figure 3-13. PETG Filament [28]

Figure 3-13 shows the filament used during the design process to house circuit components.

The circuit housing that attaches to the bar includes three main sections. The top section houses the solar cell and allows the connection pins to be accessed from below so that the battery and IMU can easily reach them. The middle section will house the battery and IMU, keeping them protected from outside interference. The bottom section mounts the system to the bar.

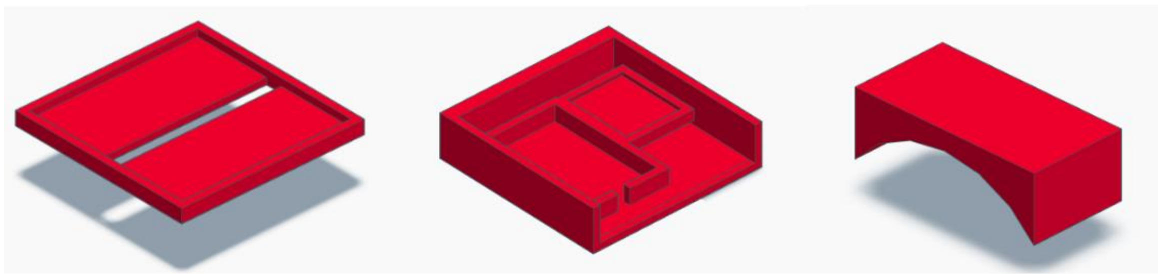

Figure 3-14. Bar-Mounted Sensor System

Figure 3-14 shows each section of the circuit housing. From left to right the top, middle, and bottom sections are shown.

3.3.5. Subsystem 5: Software Development

With a primary focus on seamless integration and ease of use, the software structure for The Workout Buddy is designed to streamline user connectivity during the workout process. Less time and less hassle in the gym translate to a better user experience overall, and the chief goal of The Workout Buddy is to make the user's gym experience as simple and rewarding as possible.

Thus, Bravo Builders' software approach for this design is divided into three partitions: the sensor system firmware, the base system software aboard the core microcontroller, and the smartphone application. Figures 3-15 and 3-16 provide visualizations of the primary application and overall software design goals, respectively.

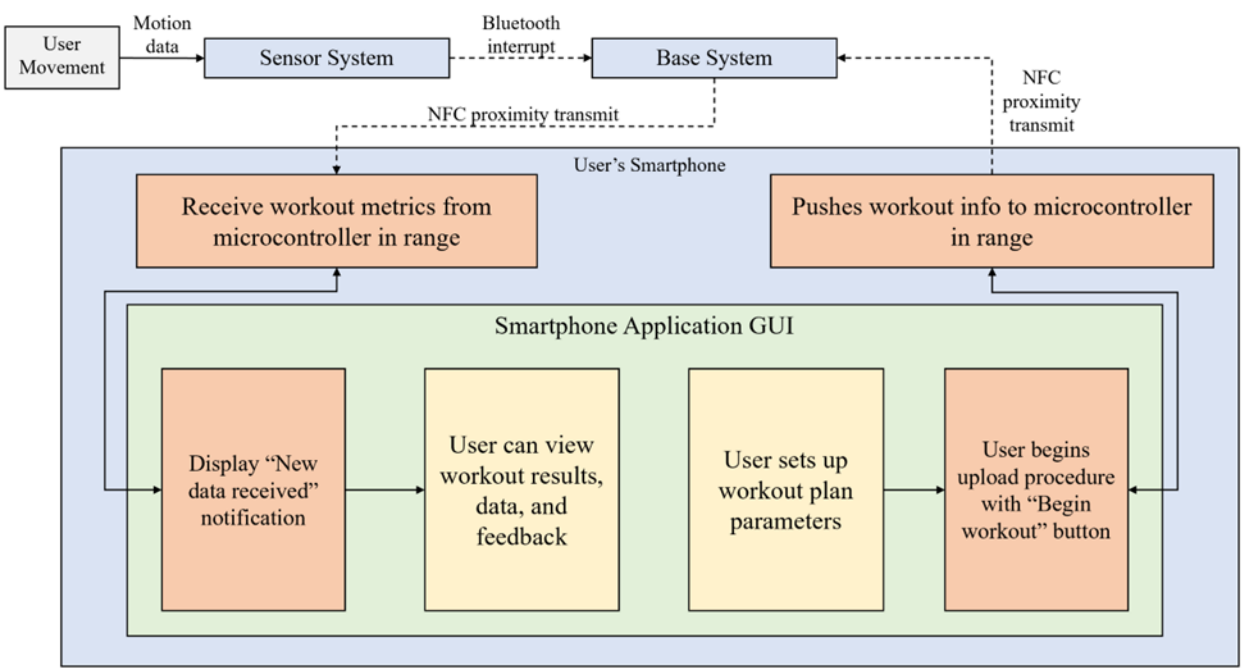

Figure 3-15. Application Design Overview

Figure 3-15 delves into the process by which The Workout Buddy's smartphone application allows the user to interface seamlessly with the base and sensor systems. All data transmissions between the user's smartphone and the mounted systems are initiated via easy-to-use, close-range NFC exchanges. Blue modules indicate individual systems, while orange modules indicate critical interactions and interrupts. Yellow modules are graphical user interface (GUI) interactions contained within the application alone.

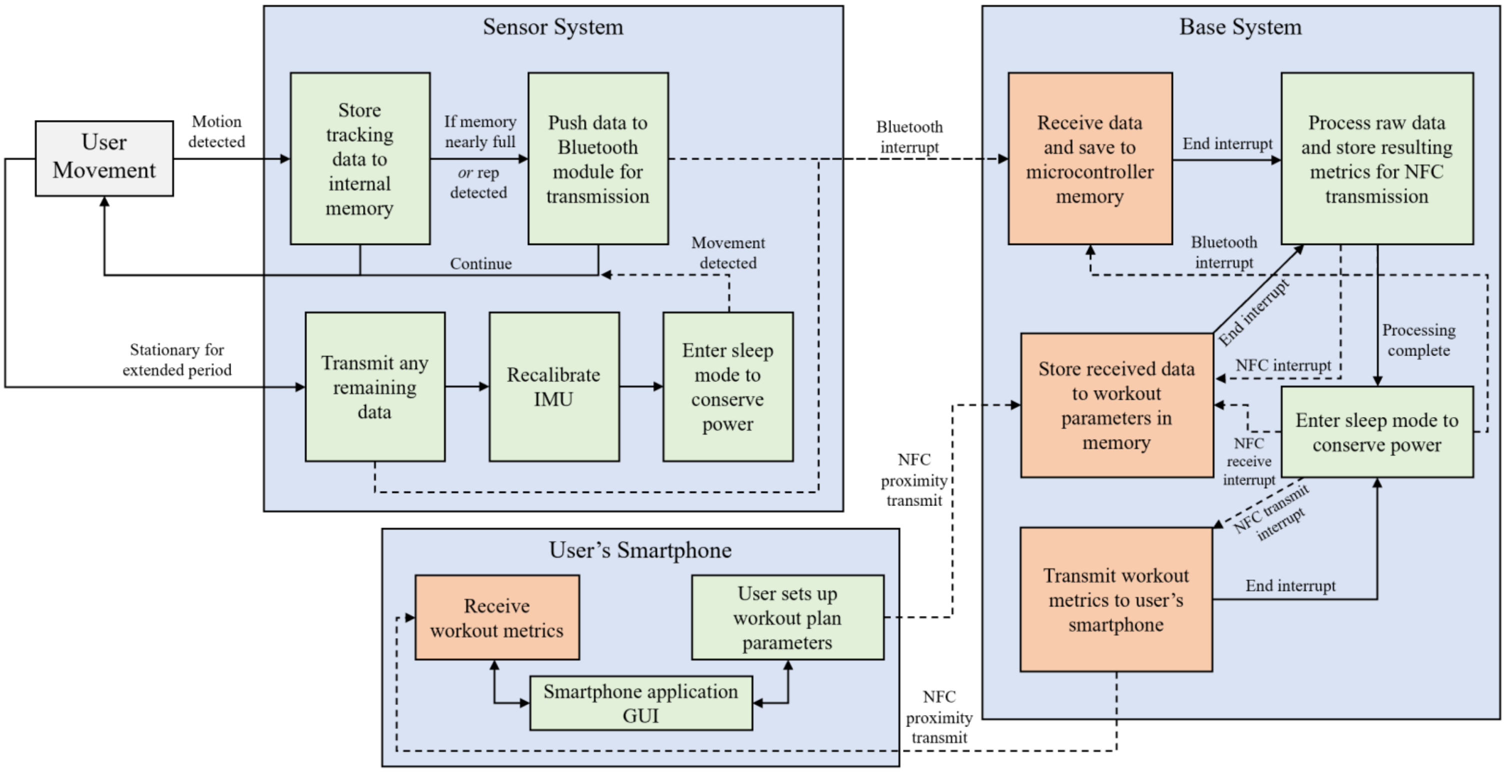

Figure 3-16. Software Design Overview

Figure 3-16 displays the intended software design concept for each partition, with an emphasis on real-time movement monitoring for optimal tracking data and mid-workout visual feedback. Orange modules and dashed lines indicate interrupts in a particular system's runtime to allow for proper transmission/reception behavior or to wake devices in sleep mode for reduced power consumption.

3.4. Level 2 Prototype Design

The Workout Buddy is an automated fitness tracker that counts reps and sets with an IMU sensor. The prototype tracks user input from an IMU sensor housed in the sensor system located on the barbell. The workout data is then transmitted via Bluetooth to the Raspberry Pi 4, housed in the base system located on the barbell rack. The user then taps their smartphone to the base system to transfer the workout data via NFC to The Workout Buddy app. The app consists of simple sign up/login asking for height, weight, age, username, and password. Based off the information entered when signing up, The Workout Buddy app gives workout suggestions, or the user can manually input a workout routine. The app has 3 tabs which include form technique, rep/set counter, and workout suggestions/workout routines.

3.4.1. Level 2 Diagram

The Workout Buddy is comprised of two main systems: the sensor system and the base system. As shown in Figure 3-17 the sensor system has two inputs and one output. The orange arrows indicate the path of how power is supplied from the solar cell to the IMU sensor as the black arrows indicate the path of data provided by the user's input. The base system has two inputs which include the output data of the sensor system and power supplied by a standard 120V outlet. The base system consists of a power entry connector that provides power to the Irm 15-5 AC-DC converter, supplying DC power to the Raspberry Pi 4, the NFC transmitter, and the Hoysond OLED screen. The base system acquires the user input data from the sensor system via Bluetooth, which in turn uses NFC to transmit from the base system to the user's smartphone. Additionally, the user's current rep and set count is displayed on an OLED screen for an easy visual display.

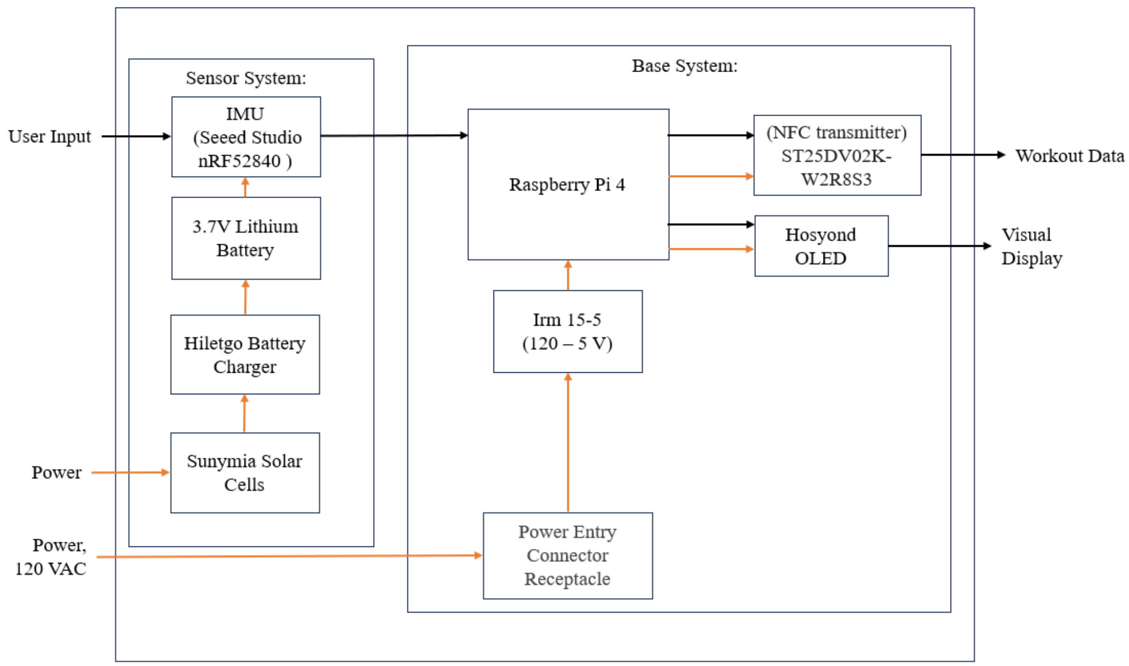

Figure 3-17. The Workout Buddy (Level 2)

The Workout Buddy serves as a free weight fitness tracker for both public and home gym use, so an important aspect of Bravo Builders is to provide a safe and reliable workout experience. To safely house the electronics, the sensor and base system use water-resistant 3D-printed material to provide protection from sweat, dust, and other factors. Every subsystem of The Workout Buddy is tested to ensure peak performance and reduce the risk of equipment failure.

3.5. REFRENCES

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