Home Fitness Aid

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Table of Contents

1 Introduction

1.1 Objective

Across the world, governments are increasingly concerned about the health of their citizens. One issue affecting the health of a population is obesity, which can increase risk for diabetes, heart disease, and cancer [1]. Furthermore, the burden put on society due to obesity is $147 billion in the United States alone [2]. According to the Centers for Disease Control(CDC), the best way to combat obesity and improve health is to increase physical activity through an exercise routine [3]. One of the greatest difficulties in starting an exercise routine is learning exercise form and counting repetitions of exercises. An improper exercise can risk injury to the individual and others. Additionally, without a system to keep track of the number and type of exercises performed, it is difficult to gauge the success of a workout plan over time. The combination of proper and regimented exercise is essential to succeed in weight management and healthy living.

Our goal is to create a wearable that can track exercises qualitatively and quantitatively. The device will consist of an accelerometer, a gyroscope, and a microcontroller. The accelerometer will track the speed and time of exercises done and the gyroscope will track the direction and angle of exercises done. The gyroscope and accelerometer will process its data through a microcontroller which will then output its data via Bluetooth to a computing unit. This unit processes the data from the wearable to create data about the form of an exercise and the number of repetitions of an exercise. The data will then display on an LCD touchscreen for the user. The user can then use this data to track and change their exercise routine.

1.2 Background

Other popular fitness wearables, such as Fitbit or Apple Watch, do not have a feature to track an individual’s exercise in quantity and quality. These devices often feature pedometers, which measures distance walked and total number of steps, but do not measure other information such as the number of repetitions of push-ups or sit-ups. Consumers often make purchasing decisions relating to electronics by comparing prices of similar products. Therefore, it is important that our device matches or is lower than the cost of these other devices which means the cost of our device must be near the project budget of $100.

This device must have the ability to track an individual’s exercise form and number of repetitions and cost a similar price to other fitness wearables whose latest models sell for about $200 and less for older models.

1.3 Visual Aid

The physical design, shown in Figure 1, consists of a wearable that is meant to be worn on the arm or leg, and a separate screen for the user interface.

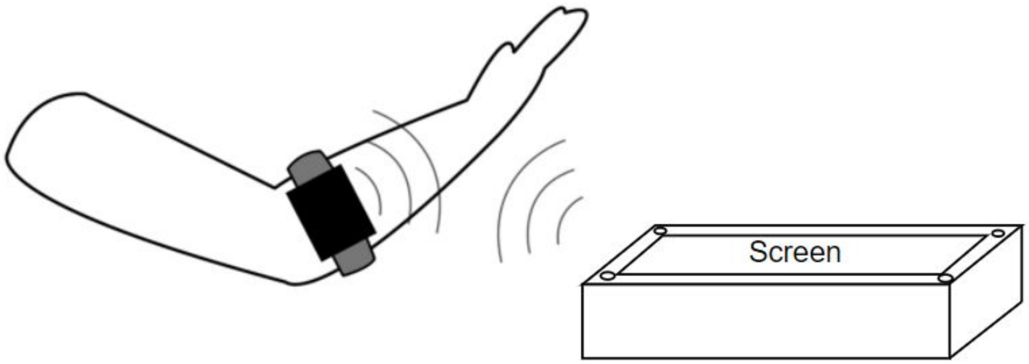

Figure 1: Sketch of Proposed Product

1.4 High-Level Requirements

High-Level Requirements:

- The number of repetitions of an exercise must match those counted by the product within an error rate of 10%.
- The product must be able to dynamically increase the difficulty of the exercise routine by increasing the repetitions every three consecutive successful workouts by a margin of error of 10%.
- The product must be able to point out suggestions to the user so that he/she can perform the exercise correctly. When over 10% of the repetitions in a set deviate from the mean of the correct form, a suggestion will be prompted on the display.

2 Design

2.1 Block Diagram

To meet its operational requirements the device is split into four units: a sensor unit, a power unit, a control unit, and a user interface. The power supply ensures that the device is powered for the duration of a few exercise sessions estimated at an hour every other day. The sensor unit contains an accelerometer and gyroscope that measures the angular velocity and linear acceleration respectively. The combination of both will ensure that repetitions are counted correctly and that exercise form information is gathered. This information is then sent to the control unit which is responsible for processing and outputting the exercise data to the user interface. Furthermore, the control unit can also receive commands from the user interface to enter a new exercise, look at data, etc. Both microcontrollers communicate via built-in Bluetooth antennas. Data from the control unit is tested to ensure that the wristband microcontroller and central microcontroller have matching data where applicable to ensure the Bluetooth connection is working correctly. The user interface is responsible for outputting data to the user through a digital display and receiving commands from the user to change the operating mode of the device. An SPI interface will handle the data transfer between the microcontroller and the display. The digital display will display all relevant information to the user and update based on information from the control unit within a reasonable timeframe.

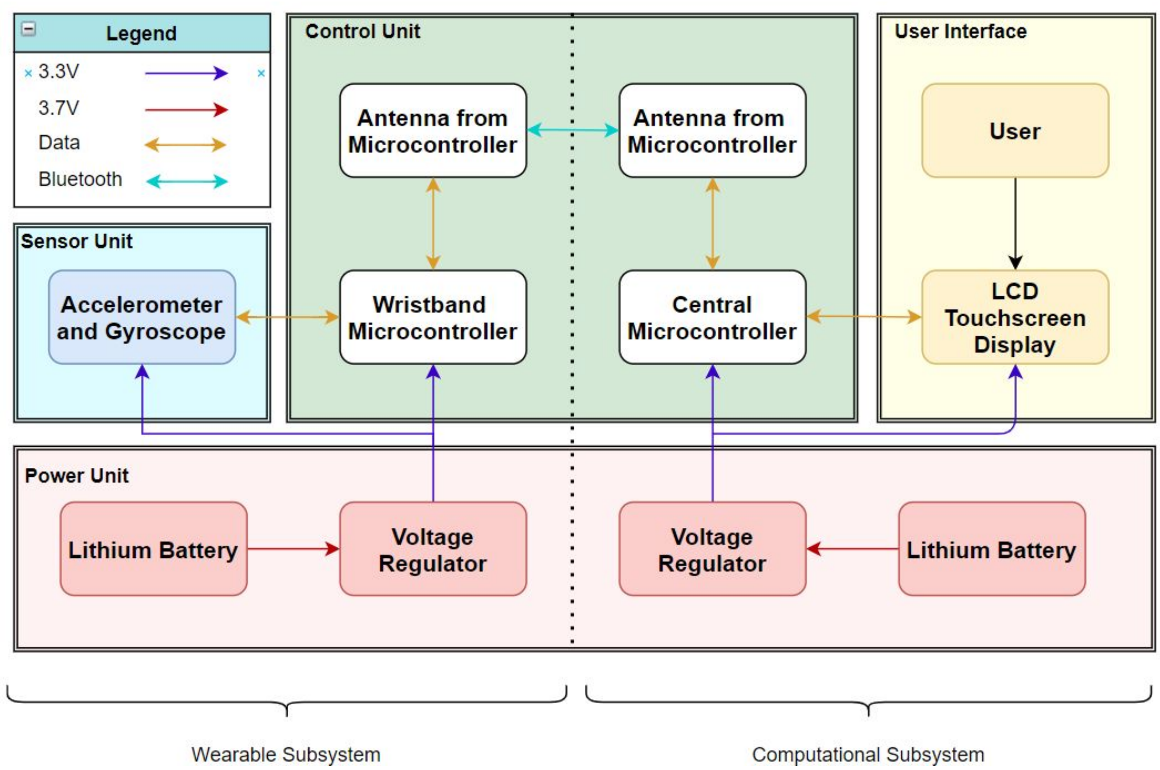

Figure 2: Home Fitness Aid Block Diagram

2.2 Physical Design

The Home Fitness Aid is composed of two separate subsystems shown below in Figure 3 and 4. The first subsystem contains the sensors for data collection and a microcontroller for data transmission. It will consist of an adjustable band with a case for the electronics attached. The second subsystem contains the LCD display and microcontroller for computing. Please note the dimensions may change for optimal compactness further in the design process.

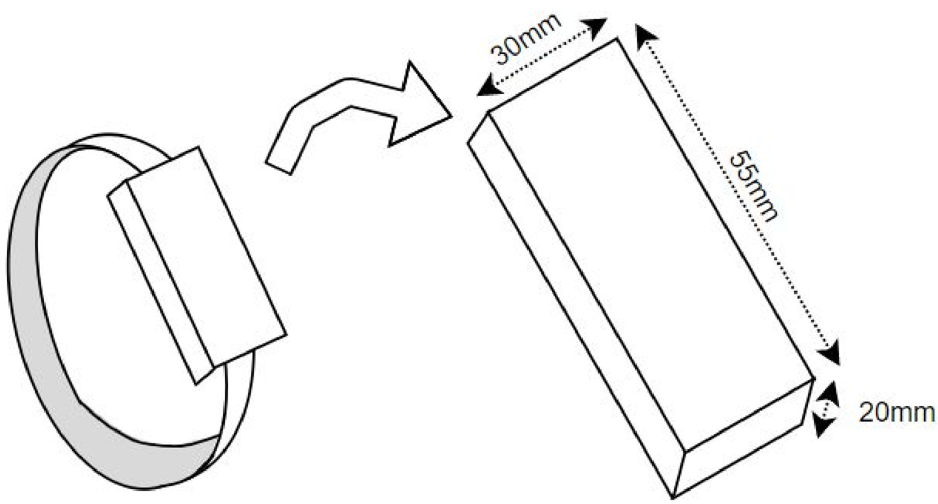

Figure 3: Wearable Dimensions

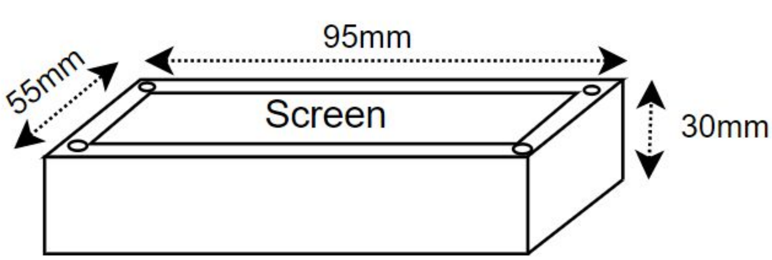

Figure 4: Computation Case Dimensions

2.3 Power Unit

2.3.1 Lithium Ion Polymer Batteries

This component will provide power for the entire device and will receive power from the battery charger. For the wristband and sensors, the battery must be able to be used for an hour every other day for at least two days. Since the wristband microcontroller and the sensor unit are estimated to require about 100 mA of current to run a battery of 350 mAh was selected for the wearable. The same principle applies to the central microcontroller and the user interface which would require an estimated 200 mA to run per hour. A much larger battery can be used in this case since these elements are not meant to be worn. Therefore, a 2000 mAh battery was selected for these elements. These batteries will provide power through the voltage regulators.

Requirements	Verification
• Provides a minimum of 350 mAh for wearable unit and sensor unit. • Provides a minimum of 2000 mAh for the computation unit.	1. Connect the 350 mAh charged battery to a power unit mock-up circuit for the wristband microcontroller and sensor unit. 2. Discharge the battery at a rate of 100 mAh. 3. Use a voltmeter to ensure the voltage remains above 3.7 V until the battery is discharged. 4. Repeat steps 1-3 with the 2000 mAh charged battery for the central microcontroller and user interface.

Table 1: Requirement and Verification of Lithium Ion Batteries

2.3.2 Voltage Regulator

The low-dropout voltage regulator is responsible for delivering a voltage of 2.7 V to the sensor unit using input voltages from the battery of 4.2 V to 3.7 V. The chip used is the TPS 77018 from Texas instruments and must be able to withstand a peak voltage of 4.2 V and a constant current of 0.45 mA. The voltage regulator operates at an efficiency of 62% with 4.2 V input voltage and an efficiency of 73% with 3.7 V input voltage.

Requirements	Verification
• Provides 2.7 V ± 10% from a 3.7 V - 4.2 V source. • Can operate at a current of ± 10% 0.45 mA.	1. Using a power unit mock-up circuit connect a 4.2 V source and draw 0.45 mA for the sensor section. 2. Measure output voltage using an oscilloscope and ensure that voltage remains ± 10% of 2.7 V.

Table 2: Requirement and Verification of Voltage Regulator

2.3.3 Battery Charger

The battery charger will charge both Li-ion batteries through a USB jack with a MCP73831 charger chip. This system will charge the wearable battery in 3.5 hours and the computational/user interface battery in 20 hours. For the charger to work correctly it must be at a higher potential than that of the battery to facilitate charging.

Requirements	Verification
• Charges Li-ion battery to 4.2-4.16 V when a continuous voltage of 4.4-7.0 V is applied.	1. Discharge a Li-ion battery to 3.7 V. 2. Charge battery from the output of the charger from an input of 7.0 V. 3. Using a voltmeter, verify that when the battery is fully charged when at 4.16-4.2 V and does not go beyond this level.

Table 3: Requirement and Verification of Battery Charger

2.4 Control Unit

2.4.1 Microcontroller

The microcontroller in the wearable subsystem is responsible for retrieving data from the sensor unit and transmitting that information to the microcontroller in the wearable. The microcontroller in the computational subsystem is responsible for receiving data from the wristband subsystem and displaying information on the LCD display. We require the Bluetooth, onboard the microcontroller, to reliably transmit and receive data from a distance of 5 meters. This distance will give the user enough space to workout while maintaining a view of the display.

Requirements	Verification
• Must successfully transmit and receive 90% of Bluetooth low-energy (BLE) packets over a distance of 5 meters.	1. Run a program that sends BLE heartbeats (1 packet per second) from one microcontroller to another at a distance of 5 meters apart. The program will be run for 1 minute and 40 seconds. 2. Use IO pins from the receiving microcontroller to display the number of packets received on the screen. 3. Divide number by 100. See if the result receives at least 90-100% of packets.

Table 4: Requirement and Verification of Microcontroller

2.5 Sensor Unit

2.5.1 Inertial Measurement Unit

The accelerometer and gyroscope are the primary means of detecting whether the user is performing his/her exercises correctly. These sensors are built into a single IMU chip (inertial measurement unit) and are used to detect linear and angular forces for all three spatial dimensions. The chosen IMU model is LSM6DSL. This IMU takes measurements from each sensor specified above at a maximum frequency of 6664 Hz. It also offers high precision for the accelerometer (minimum precision is $6.1 * 10^{-5}$ G-Force) and for the gyroscope (minimum precision is $4.375 * 10^{-3}$ degrees per second). For the purpose of this product, we will not need high precision because human motions during an exercise are at relatively low speeds. We will base the sensor's sampling rate, acceleration, and degrees per a second requirements on a typical bicep curl. We will define a bicep curl as a movement of the arm from a range of 90 degrees. A typical bicep curl will take approximately 2 seconds to complete a full repetition.

Requirements	Verification
• The inertial measurement unit must sample data at a rate of at least 50 measurements a second. • Accelerometer must have a precision of at least ± 1.0 m/s^2. • Gyroscope must have a precision of at least 0.01 degrees per second. • The noise of the gyroscope must be less than ± 0.005 degrees per second.	1. Test sampling rate: a. Test sensor by connecting it to a development board and run it at a high frequency mode (should be greater than 100 measurements per second). b. Count the number of measurements every second through the development board. Display that number through a computer screen. 2. To test the precision of the accelerometer, drop the sensor onto a soft surface at a height of less than 1 meter. Check if the measurement matches 9.8 m/s^2 with a margin of error of ± 1.0 m/s^2. 3. Tests for gyroscope: a. Simply place the sensor unit on a flat surface. Read the incoming data and ensure

	that the noise does not surpass 0.005 degrees per a second. b. Place the sensor on a table. Steadily rotate it by 90 degrees over 3 seconds. Check if the measurement matches 30 degrees per second with a margin of error of ± 0.01 degree per second.

Table 5: Requirement and Verification of Accelerometer and Gyroscope

2.6 User Interface

2.6.1 LCD Display

The LCD display will be the means of communication between the user and the product. The display will visualize the exercise's sets, repetitions, and allow for user input. The chosen display is the ILI9341 with a colored 240x320 resolution and 2.8-inch resistive touchscreen display. We require the display to be at least 40x50 mm large to have good viewability during an exercise routine. The display will utilize serial peripheral interface (SPI) to communicate with the microcontroller.

<table>
<tr><th>Requirements</th><th>Verification</th></tr>
<tr><td>

Active screen area must be at least 40 x 50 mm large.
The pixels per inch (PPI) must at least be 100 for readability.
Touchscreen must be functional and accurate within an error of ± 8 pixels.

</td><td>

Measure the dimensions of the active screen area with a ruler
To test readability:
<ol type="a">
Try to display 3mm tall ASCII characters on the screen. Check if the font is clear and readable.
To find PPI, take the pixels of the length of the display and divide by the measured length in inches.

To test the accuracy of the touchscreen:
<ol type="a">
Have the microcontroller load a single chosen pixel and note the coordinate
Use a stylus to pinpoint and touch the pixel on the screen
Read coordinates from the microcontroller and ensure it is within 8 pixels radius of the original pixel within a margin of error of ± 10%.

</td></tr>
</table>

Table 6: Requirement and Verification of LCD Display

2.7 Cases

2.7.1 Wearable

This component will house the sensors and a communication unit. It is an adjustable band with the case attached. Its primary purpose is to be a comfortable wearable to allow the components inside to gather data during an exercise routine.

Requirements	Verification
• Band must comfortably fit a person's arm or ankle from a circumference of 6 inches and 10 inches. • Case must weigh less than 1.5 pounds.	1. Measure the circumference of the band at its smallest form, and once again at its largest stretched. Ensure the values of 6 inches and 10 inches are within this bound. 2. Place the finished wearable with electronics on a scale to measure weight. Ensure it is less than 1.5 pounds within a margin of error of ± 10%.

Table 7: Requirement and Verification of the Wearable

2.7.2 Processing Unit Case

This case will house the LCD display and a computation unit. The primary purpose of this unit is to provide an interface interaction with the user and to protect the LCD display and computation unit.

Requirements	Verification
• Must weigh less than 3 pounds for portability.	1. Place the finished case with electronics on a scale to measure weight. Ensure the weight is less than 3 pounds within a margin of error of ± 10%.

Table 8: Requirement and Verification of Processing Unit Case

2.8 Schematics

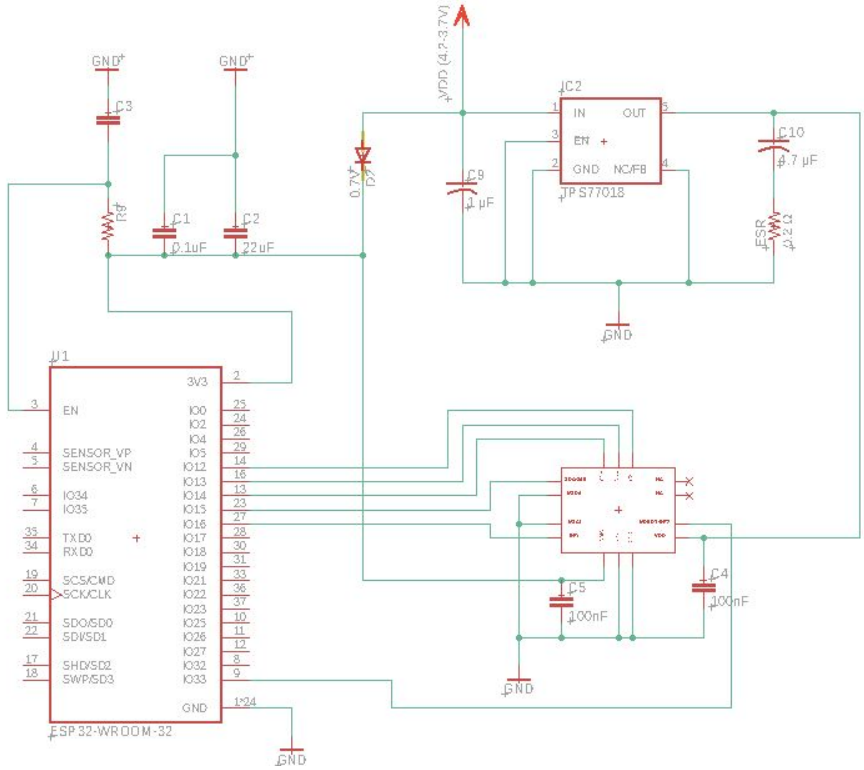

Figure 5: Schematic of wristband subsystem

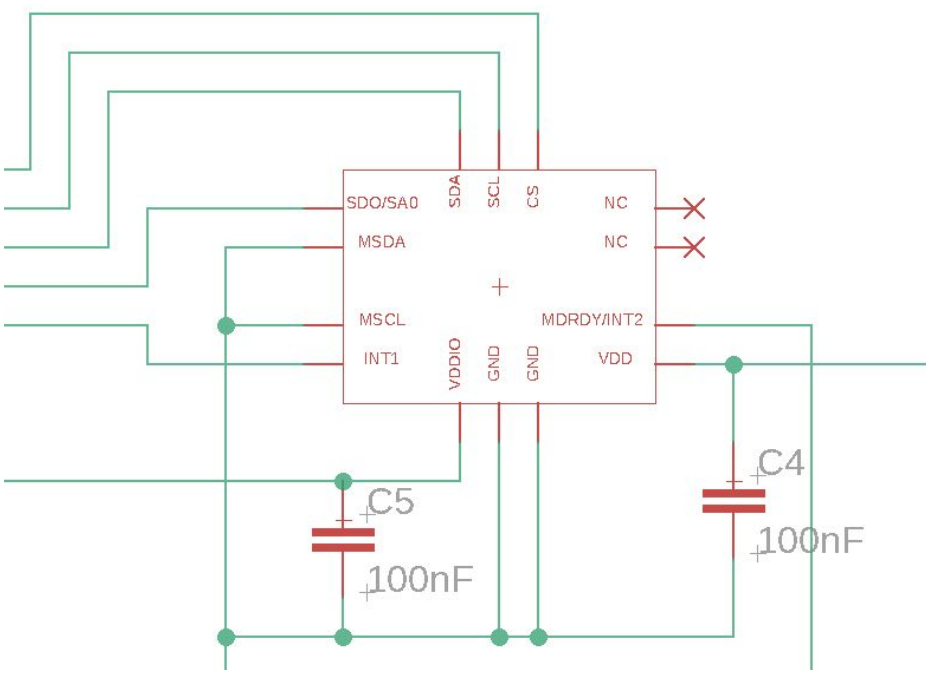

Figure 6: Schematic magnified at sensor unit

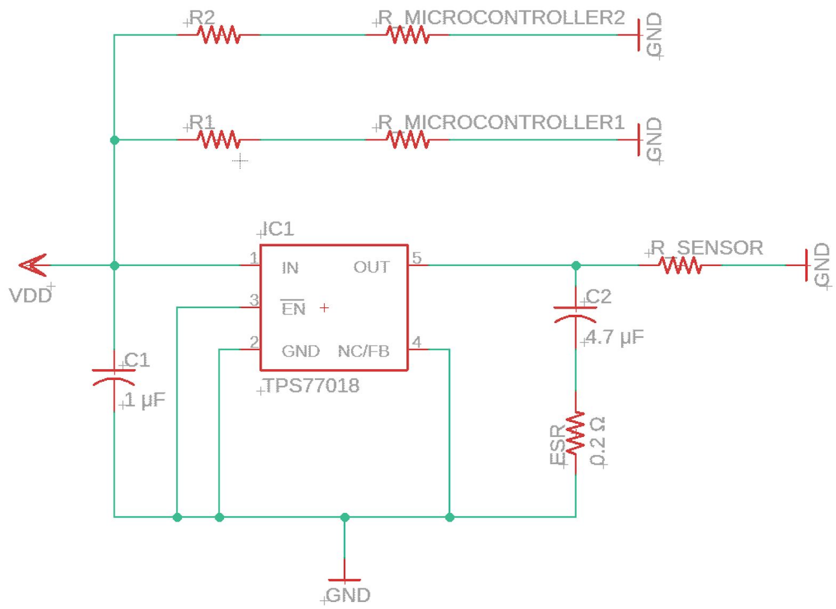

Figure 7: Schematic of power unit

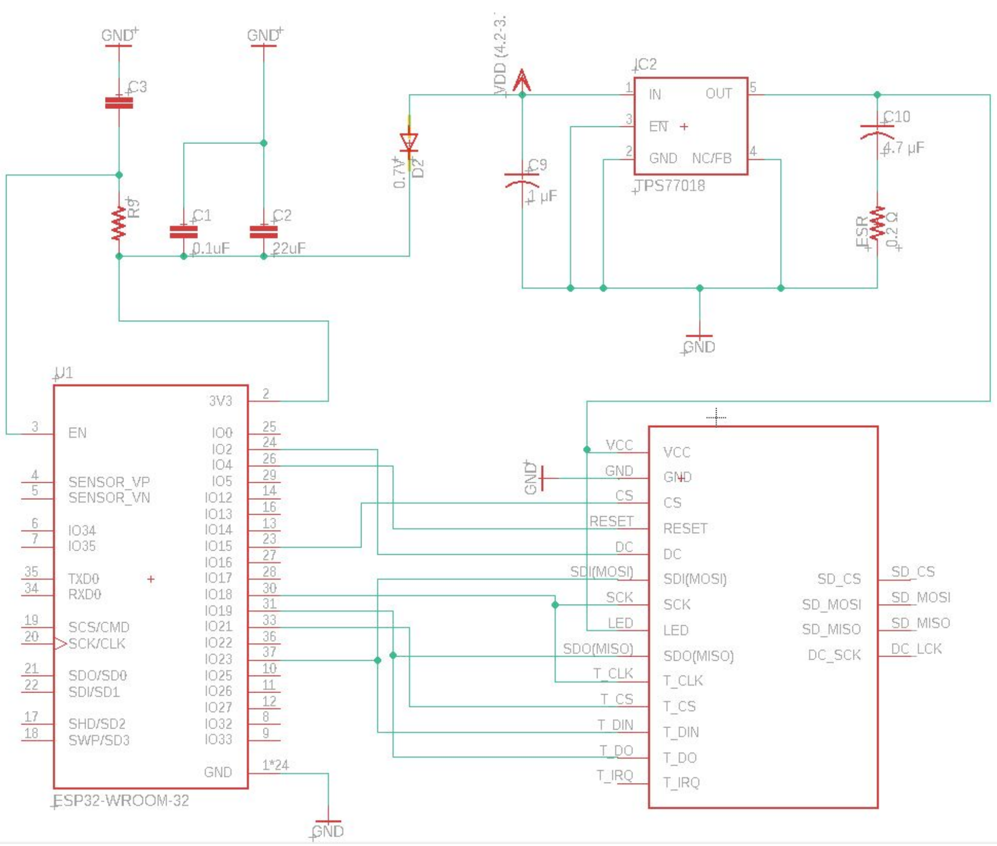

Figure 8: Schematic of computation subsystem

2.9 Tolerance Analysis

The most critical feature of the *Home Fitness Device* is the precision of measuring each exercise by the accelerometer and gyroscope. For the simplicity, our tolerance analysis will focus on determining the user's body form for a standing bicep curl.

For this analysis, we will assume that all data gathered from this research article is accurate [8]. Here is a table from this study that describes the range of motion of the elbow for this exercise.

				Statistic	Std. Error
Range of Motion (deg)	Standing Curl	Mean		122.15	1.65
		95% Conf Int for Mean	Lower Bound	118.82	
			Upper Bound	125.48	
		Median		122.39	
		Std. Deviation		11.08	
		Minimum		99.43	
		Maximum		146.32	
		Skewness		0.12	0.35
		Kurtosis		-0.43	0.69
	Incline Curl	Mean		110.29	1.40
		95% Conf Int for Mean	Lower Bound	107.45	
			Upper Bound	113.12	
		Median		109.48	
		Std. Deviation		9.10	
		Minimum		94.47	
		Maximum		135.17	
		Skewness		0.54	0.37
		Kurtosis		0.31	0.72

Table 9: Range of Motion of a Standard Arm

Table 9 only shows a 95% confidence interval for the mean range of motion. But we want a 90% confidence interval to allow a margin error of ten percent when our device is counting the repetitions. From this study, we have obtained few variables which are used to calculate the interval.

- Number of samples, $n = 45$
- Mean, $\bar{x} = 122.15$
- Standard deviation, $\sigma = 11.08$

The lower bound of the interval is $\bar{x} - T \times \frac{\sigma}{\sqrt{n}}$, where T is the t value for 90% confidence with degrees of freedom, $df = n - 1 = 44$. Here, $T = 1.68$. Similarly, the upper bound of the interval is $\bar{x} + T \times \frac{\sigma}{\sqrt{n}}$. Using these calculations, we get an interval of [119.38, 124.92].

Note that this result only talks about the range of motion in degrees, not degrees per second. Our gyroscope can only measure the angular velocity of the elbow. To obtain the angular displacement, we can use the following equation

$$\theta = \sum_{t=1}^{f \cdot p} \frac{\omega(t)}{f \cdot p}$$

Here, θ represents the total angular displacement between the resting position and the exertion position of the elbow. The variable $\omega(t)$ represents the angular speed taken at time frame t, the variable f represents the frequency of measurements, and the variable p represents the period between the resting position and the exertion position of the elbow.

For the sake of simplicity, we will assume that the period p is one second. We will also assume that the angular speed measured by the gyroscope will almost always be consistent with the average angular speed during each repetition, provided that f is sufficiently large ($f \geq 1000$). Given these two assumptions, we can use the same interval that we have calculated for estimating the angular speed.

- Look into the period of a bicep curl. Add a diagram to explain resting position.

To ensure we can stay within this confidence interval (which has a precision of two decimal places), our gyroscope must have a precision of at least 0.01 degrees per second and the noise should be no more than ± 0.005 degrees per second.

3 Costs and Schedule

3.1 Cost Analysis

3.1.1 Labor

The main factor to the project's cost is labor. A graduate from UIUC's ECE program will typically start with an average salary of $88,000 or approximately $42/hr [5]. The design, manufacturing, testing, and documenting of the product will take approximately 14 weeks. Our team will approximately contribute about 15 hours per a week per person. The table below will summarize the costs.

Name	Hourly Rate	Hours	Overhead Costs	Total
Andrew Garcia	$42.00	210	x2.5	$22,050
Hemanth Ravi Gowda	$42.00	210	x2.5	$22,050
Steve Cheng	$42.00	210	x2.5	$22,050
Machine Shop	$56.12	6	x1.0	$336.70
			Total Labor Costs	$66,486.70

Table 10: Labor Costs

3.1.2 Parts

Qt.	Part #	Manufacturer	Description	Price	Total
2	ESP32-WROOM-32E	Espressif Systems	Dual-core 32-bit microprocessor with 4 MB SPI flash, SPI interface, Bluetooth LE, and Wi-Fi capabilities	$2.80	$5.60
1	ILI9341	HiLetgo	2.8" SPI TFT LCD Display with resistive touchscreen capabilities	$13.99	$13.99
1	LSM6DSL	STMicroelectronics	Accelerometer and gyroscope sensors	$3.98	$3.98
2	TPS77018	Texas Instruments	Voltage regulator	$1.14	$2.28
1	2750	Adafruit Industries	Lithium Battery 3.7V 350mAh	$6.95	$6.95
1	2011	Adafruit Industries	Lithium Battery 3.7V 2000mAh	$12.50	$12.50
1	1904	Adafruit Industries	Lithium Ion Polymer Charger Board	$6.95	$6.95
				Total of all parts:	$52.25

Table 11: Parts Costs

3.1.3 Grand Total

Table 12 below summarizes the total costs of labor and parts required for the completion of this product.

Section	Costs
Labor	$66,486.70
Parts	$52.25
Grand Total	$66,538.95

Table 12: Total Cost

3.2 Schedule

Week	Andrew	Hemanth	Steve
9/28	Design power subsystem.	Create schematic for wearable subsystem	Order all electronic parts required. Acquire dimensions for machine shop assembly.
10/5	Get parts to test power unit. Version 1 power system design completed.	Learn to program microcontroller	Create schematic for microcontroller and display.
10/12	Test power unit parts. Prepare mock-up.	Use dev board to test BLE functionality, sensors, and programs that will be used by the microcontrollers	Assemble test fixture for the microcontroller devkit and display.
10/19	Refine power unit. Test with Hemanth's and Steve's prototypes.	Test microcontroller functionality in the integrated systems	Develop drivers for visuals and touchscreen. Begin user interface.
10/26	Version 2 power system design completed.	Microcontroller and sensor configuration design completed. Look for optimization to	Develop a system for writing images with low data usage.

		reduce energy consumption	
11/2	Test version 2 design. Design or improvement of version 2.	Test final configuration	Continue development of UI. Test and debug final design of PCB for microcontroller to display.
11/9	Figure out placement of power unit in prototype case.	Research data required to check if exercise is done correctly	Verification of subsystems and high-level requirements. Debug if needed.
11/16	Conduct final testing of the whole prototype with the group. Prepare for demonstration.	Conduct final testing	Prepare for demonstration on Wed-Fri.
11/23	Collect data on power consumption and voltage and current of loads. Assist group members in any relevant data gathering.	Find improvements in data collection process from sensors	Make final adjustments and future plans from critiques.
11/30	Prepare for final presentation. Begin final paper.	Prepare for final presentation. Begin final paper.	Prepare for final presentation. Begin final paper.
12/7	Final paper submission.	Final paper submission	Submit final paper and evaluate completion of all assignments.

Table 13: Group Schedule

4 Ethics and Safety

There are some common safety hazards in the development and usage of this product. This section will address these safety hazards and our plans to avoid any dangers. We will also address any ethical concerns that could result from the daily use of the product. The IEEE Code of Ethics will be used as a standard to judge any ethical and safety hazards that may emerge.

The first issue we will address is the safe usage of lithium batteries. Lithium batteries present a fire and explosion hazard if they are damaged or not properly managed. We will ensure in our design that the battery will be held in a safe location, and is not susceptible to small falls. Furthermore, we will take precautions to store the device in an environment where the lithium batteries are not subject to temperatures above 45 degrees Celsius or below 0 degrees Celsius where there is a possibility of thermal runaway and explosion. Insulating material will be extensively used to ensure short circuiting is not possible. Extensive testing of the circuitry will also occur to ensure the battery is not subject to voltages above its tolerances which can lead to cathode breakdown and a release of thermal energy. To properly charge the lithium battery, we plan to use Adafruit's battery charger at the recommended current [7]. Since we are also using Adafruit's batteries, the charging combination is stable. Lastly, IEEE Code of Ethics #1 states that one must "disclose promptly factors that might endanger the public or the environment" [4]. Since lithium batteries are a known environmental risk, we must ensure the used batteries are disposed of in a proper manner. We will also inform users of the device that it contains lithium batteries and is a hazard to the environment if not disposed of correctly.

According to IEEE Code of Ethics #1, one should act in a way to "protect the privacy of others" [4]. Since this device tracks a user's fitness routine it is important to ensure that the user's information is not shared with others without a user's consent. During the development of the project, care will be taken to ensure any information gathered is not shared with third-parties and if this proves to be impossible, the users will be informed of what and with whom their data is shared. Furthermore, IEEE Code of Ethics #3 states that one should "avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist" [4]. Therefore,the users must know that we do not intend to profit off any of the data and that any data generated belongs to them.

This device is also not intended for use outside or to be exposed to water. We will not test or use this device outside and information will be provided to the user stating that outdoor use or water exposure will damage the device.

Lastly, according to IEEE Code of Ethics #9, one should “avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses” [4]. This device has users exercise to generate information about their fitness routine. As exercise is a known cause of various physical injuries, it is important to inform users about risks related to exercise and advise certain at-risk groups to avoid using this device. We will ensure to follow IEEE Code of Ethics #7, which states to not engage in discrimination, to ensure that all groups told to avoid using this product are groups that are scientifically verified to be at-risk for exercise such as pregnant women or young children [4]. Furthermore, as this device is a wearable, we will choose a material for wearing the device that does not irritate the skin and design the device so the users are not injured if they fall on the device such as choosing an appropriate encasing for the device and avoiding sharp edges in the design.

These mitigation strategies fulfill the standards set by the IEEE Code of Ethics. Ultimately, there are many risks associated in the use of a wearable to facilitate exercise but we believe that the benefits outweigh the risks.

5 Contingency Plan

Due to the ongoing coronavirus epidemic, there are concerns that the college may go online for the semester. With this concern, we have prepared a contingency plan to go in effect if the semester proceeds to be fully online. Once the announcement for an online semester is made the acquisition of tools and parts needed will begin. If the ECE lab becomes unavailable an ADALM board will be acquired in order to continue testing and measuring at home. An ADALM cannot read negative values, and can be used for this project since the project will only use positive DC power. Furthermore, if the soldering for the project is incomplete, then a soldering kit will be acquired to finish soldering the project at home. The remaining labor will be divided amongst the members of the team as follows: Steve Cheng will take care of the programming for the central microcontroller in the control unit and the digital display in the user interface along with designing schematics for both units; Hemanth Gowda will take care of programming for the wristband microcontroller in the control unit and the programming for the sensor unit along with designing schematics for both units; and Andrew Garcia will take care of testing and verifying the power unit and soldering, testing, assembling, and verifying the whole device. For this division of labor to occur effectively duplicates of parts will need to be acquired depending on the progress of the project before the announcement was made. Lastly, two of our team members, Andrew Garcia and Hemanth Gowda, plan to remain on campus if the announcement goes into effect. This fact means that if resources are still available at the ECE building then much of this contingency plan will be unneeded. Therefore, this contingency plan will only go into effect if the ECE department plans to eliminate lab access for undergraduates when the university goes online. Overall, we believe that this plan will ensure the success of our project in case of an online semester.

6 Citations

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