Forma: The Smart-Clip
ECE 445 Design Document - Spring 2026

Team #82

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1. Introduction

1.1 Problem

Free weight exercises such as dumbbell and barbell lifts require significant concentration, coordination, and balance. Unlike guided gym machines, free weights do not restrict motion, meaning users must control stability and alignment entirely on their own. During complex lifts, users cannot safely look at phones or screens for visual feedback without risking improper posture or injury. As a result, there is no practical way for them to receive real-time corrections while maintaining proper focus and positioning. Beginners in

particular often struggle with poor form, including lateral wobbling, excessive wrist tilt, or using momentum instead of controlled muscle engagement. These issues are difficult to self-diagnose, especially without a personal trainer observing the movement. Over time, improper form can reduce workout effectiveness and increase the risk of strain or long-term injury. Therefore, there is a clear need for a system that can monitor form continuously and provide immediate feedback without requiring visual attention.

1.2 Solution

The proposed solution is Smart-Clip, a compact IoT attachment designed to clip securely onto dumbbells or barbells. The device uses a 6-axis IMU sensor, which includes both an accelerometer and gyroscope, to measure motion, tilt, and stability during each repetition. An ESP32 microcontroller processes this sensor data in real time and applies filtering and form-analysis algorithms to evaluate lift quality. When a repetition is completed, the system determines whether the motion remained stable or exceeded a predefined wobble threshold. A piezoelectric buzzer then provides immediate auditory feedback, emitting a clean tone for good form or a dissonant alert for excessive wobble or unsafe acceleration. Because the feedback is audio-based, the user can maintain proper head and body positioning without looking away from the lift. In addition to real-time coaching, the system transmits workout data via Bluetooth to a companion mobile application for post-workout analysis. This combination of instant correction and long-term tracking enables safer training, improved technique, and measurable performance improvement over time.
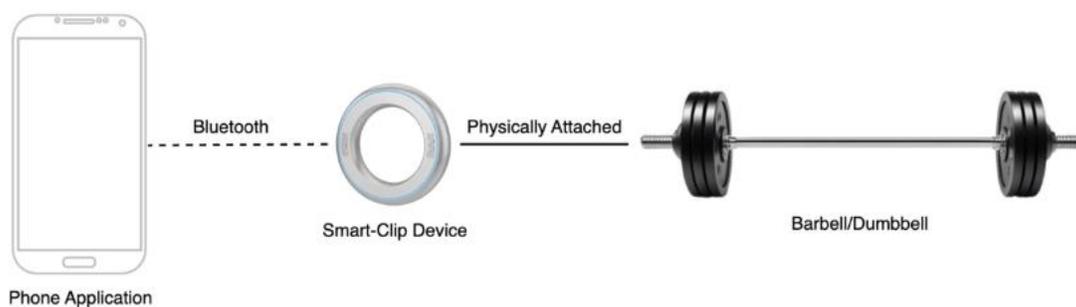
1.3 Visual Aid

Figure 1. High level Visual Aid.

The visual aid demonstrates how the Smart-Clip fits into a standard workout setup. The main hardware component, the Smart-Clip itself, is designed to be physically attached directly to the barbell or dumbbell. Placing it on the outer sleeve of the weight, rather than the handle, keeps the device clear of the user's grip while allowing the built-in IMU to accurately track every movement. A solid line represents this secure physical connection to the lifting equipment. At the same time, a dotted line leads to the Phone Application, representing the Bluetooth (BLE) connection. This layout shows how the device handles real-time data processing for instant auditory feedback on the spot, while the app stays synced to record stats like rep counts and stability scores for review after the set is finished.

1.4 High-Level Requirements

To consider our project successful, our safety suite must fulfill the following:
1. The Smart Clip must count bicep curls with at least 90% accuracy and detect wobble greater than 15 degrees in at least 9 out of 10 trials. It must not generate false alerts during clean, controlled repetitions.
2. Audio feedback must occur within 200 milliseconds of the IMU detecting rep completion. This ensures the system feels real-time and responsive to the user's movement.
3. 100% of completed sets must be transmitted correctly to the mobile app within a 5-meter range. No workout data should be lost during wireless communication.
4. The clip must rotate less than 10 degrees on the handle during a 10-repetition set. This ensures accurate sensor readings and consistent alignment.
5. The device must operate continuously for at least 1 hour on a single charge. This guarantees it can last through a full workout session without interruption.
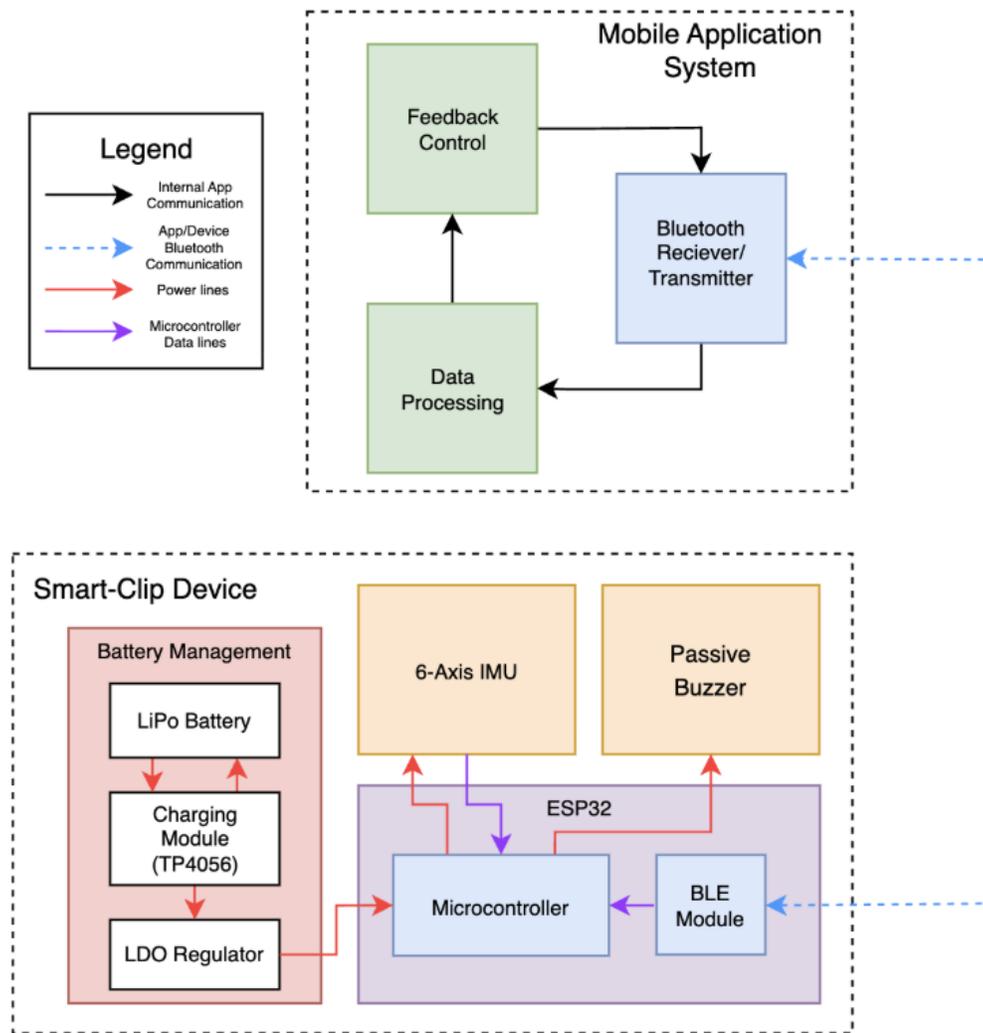
2. Design
2.1 Block Diagram

Figure 2. Block Diagram for Smart-Clip System.

2.2 Physical Design

The physical design of this Smart-Clip system is engineered to balance the structural integrity of the clip along with the proper support housing for high-precision data collection from the 6-axis IMU. This clip is designed to ensure the device remains accessible for prototyping and iterative testing as all the structural components and housing parts will be 3D printed. This will allow for lightweight, custom-fitted enclosure that will securely slip onto standard barbells and dumbbells without adding significant weight or bulk.

As shown in Figure 3, the device features a dedicated internal mounting bay (housing) for the PCB and battery. The PCB will contain all the support required for the following components:

- Microcontroller & 6-axis IMU – positioned close to the center of the clip so that the IMU can capture clean data.
- Audio Feedback (Buzzers) - placed on the pcb to provide real time auditory alerts/feedback to the user for form correction.
- Battery Management – the TP4056 and LDO regulator are strategically placed and connected to PCB to allow for 9V battery integration.
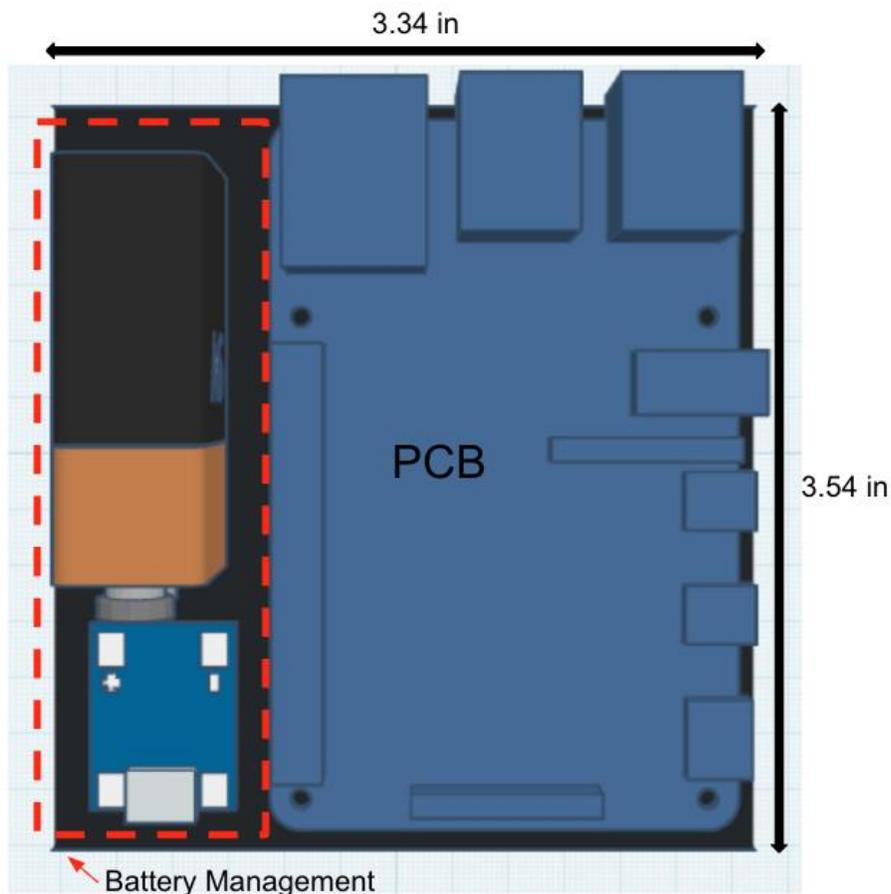
Figure 3. Smart-Clip 3D model top view.

The Smart-Clip is engineered to meet high-level requirements for precise IMU data collection. By mounting the device on the outer sleeve of a barbell, the design ensures the user's grip remains unobstructed while the internal rubber lining prevents the clip from shifting or rotating. This stability allows the system to maintain a fixed orientation, enabling it to achieve 90% rep-count accuracy and reliably detect wobbles exceeding 15 degrees. Figures 4 and 5 illustrate the front and side 3D model views of the device.

Figure 4. Smart-Clip 3D model front view.
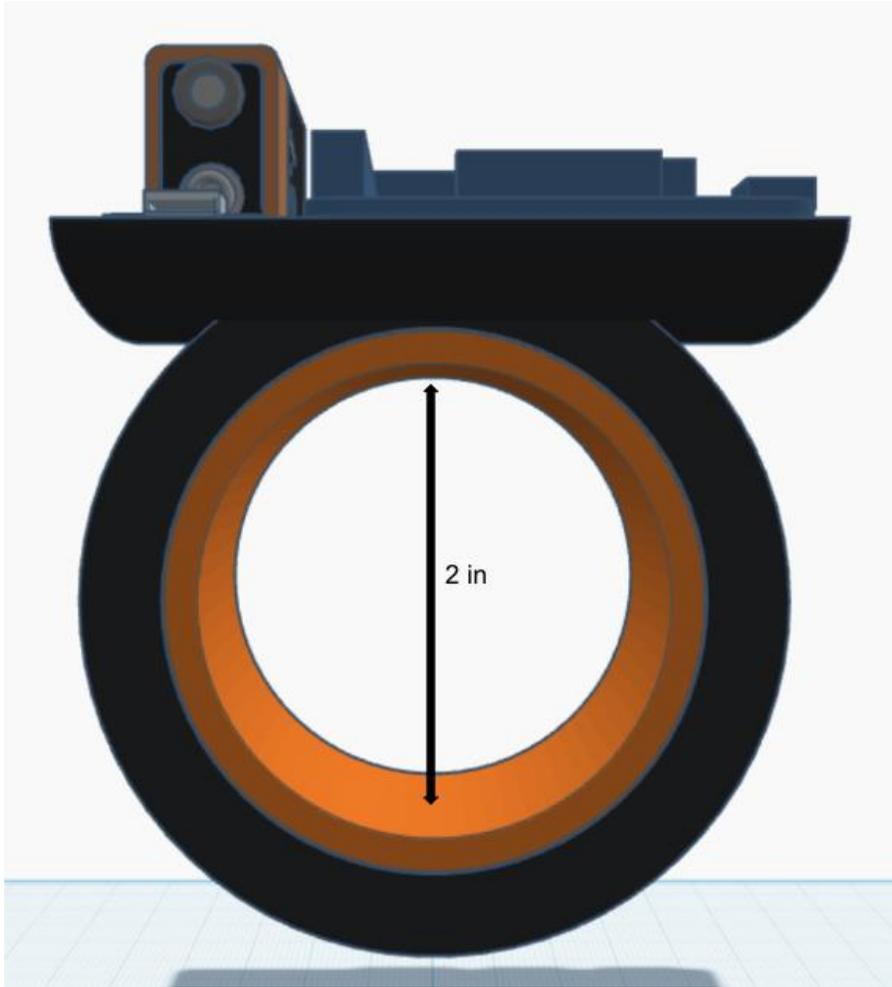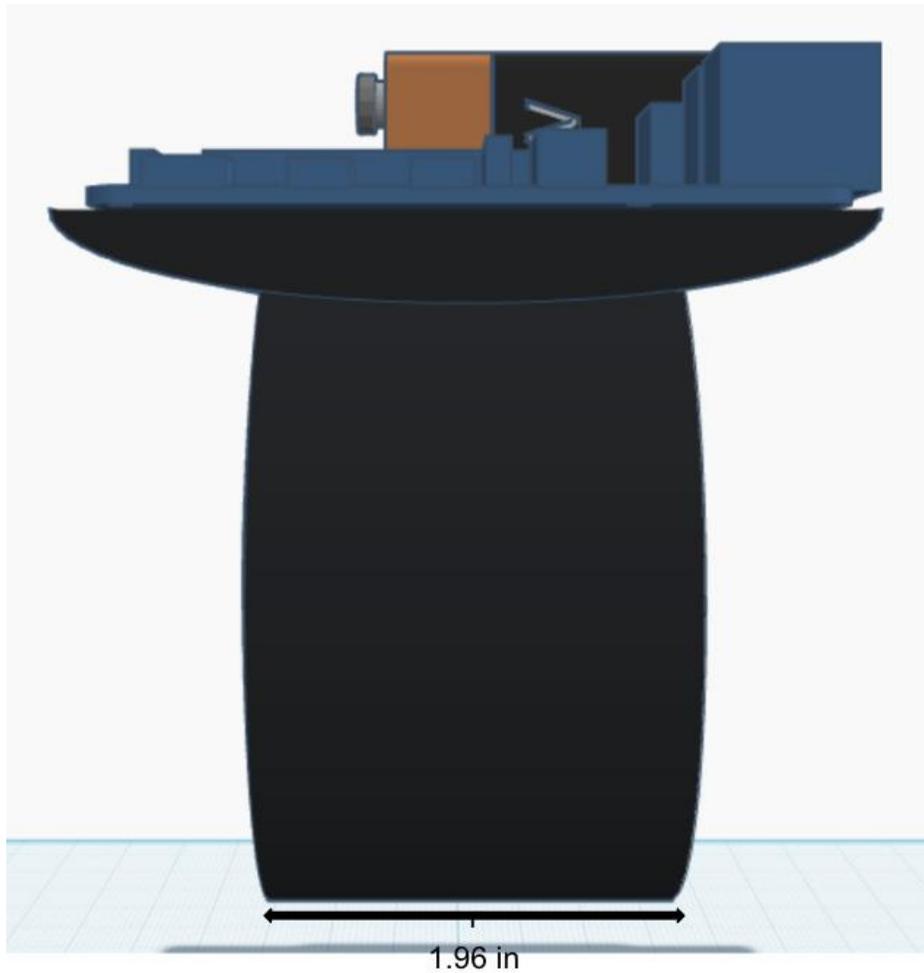
Figure 5. Smart-Clip 3D model side view.

2.3 Subsystems

2.3.1 Mobile Application

Users receive workout data from their Smart-Clip through the mobile application. While a user performs a workout, their Smart-Clip uses Bluetooth Low Energy (BLE) to send workout IMU data to the app. The mobile application is designed to make tracking your performance easy and checking your progress simple. The application is intended to help you assess how you performed but does not provide any type of control for the Smart-Clip after each use.

As illustrated in Figure 5, the mobile application receives real-time IMU data from the Smart-Clip. The application utilizes backend scripts to analyze this incoming data, providing both the user and the device with real-time acceleration metrics, repetition

counts, and stability ratings.

Figure 5. Smart-Clip Demo Mobile Application.

Subsystem Requirements	Verification
1. BLE Data Reception & Display: The mobile application must receive data from the Smart-Clip via Bluetooth Low Energy (BLE).	• Mobile application is actively paired with the Smart-Clip via BLE and a brief workout is performed. • Confirm that the app is receiving real-time metrics from the Smart-Clip by monitoring the data logs.
2. Real-Time Processing: The application must use backend scripts to analyze incoming IMU data to provide real-time	• Connect mobile app to the Smart-Clip which is actively in motion. • Then, monitor the app's live dashboard while performing a lifting set.

acceleration, repetition counts, and stability metrics.	• Confirm that the interface updates with real-time acceleration, rep counts, and stability ratings.

Table 1. Mobile Application Requirements & Verifications.

2.3.2 Power Management System

The Power Management Subsystem is responsible for managing the energy flow from the 3.7V LiPo battery to the rest of the electronics. It consists of a TP4056 charging controller that charges the battery through USB-C and a 3.3V Low Dropout (LDO) regulator that steps down the fluctuating battery voltage to a stable 3.3V required by the ESP32. This subsystem connects to the ESP32.

Subsystem Requirements	Verification
1. Input to Battery Charging Interface: Accepts 5V DC at up to 500mA through USB-C for charging.	• Make sure the partially discharged battery is connected to the power management subsystem. • Then, plug in a USB-C power source into the charging interface. • Confirm using multimeter that the input voltage is 5V at up to 500 mA.
2. Battery Charging Interface: Provides 4.2V (max) for charging and accepts 3.0V to 4.2V for discharging.	• Ensure device is charging. • Then, measure the voltage directly across the battery terminals and confirm it does not exceed 4.2V. • Next, disconnect USB-C charging, and observe if the device operates normally under the correct voltage range.
3. Regulated Output Interface: Supplies a continuous 3.3V to the ESP32 with a maximum current capacity of 1000mA.	• Ensure the LDO regulator is powered by either the battery or the USB-C power. • Then, confirm with a multimeter that the output voltage remains at a stable 3.3V across the entire current (0-1000 mA) range.
4. Over-Discharge Protection: The subsystem must mechanically disconnect the battery load if the cell voltage drops below 2.4V to prevent chemical degradation.	• Make sure a variable DC power supply is connected to the battery terminals (not the normal LiPo battery) to simulate a discharging cell. • Then, monitor the output voltage to the load while gradually lowering

| | the power supply voltage from 3.0V down to 2.4V. |
| | • Finally, confirm that the power to the load drops to 0V the moment the simulated battery voltage falls below 2.4V. |

Table 2. Power Management System Requirements & Verifications.

2.2.3 Central Processing and Control Subsystem

The ESP32 is the microcontroller of the Smart-Clip, and it manages the overall function of the device. It collects data on motion from the IMU sensor and processes it to monitor whether an exercise has been repeated as well as determine if the body exhibited any form of wobbling. The ESP32 also sends workout data to the mobile app using Bluetooth Low Energy (BLE). Lastly, the ESP32 is responsible for controlling the audio feedback from the buzzer to let the user know if their exercise form is good or poor.

Subsystem Requirements	Verification
1. Power Interface: Accepts a regulated 3.3V input and must operate within a current draw range of 80mA (idle) to 240mA (peak BLE transmission).	• Connect microcontroller to the 3.3V LDO regulator output. • Then, use a multimeter in series to measure the current draw while the device is in a standby (idle) state (draw should be 80 mA). • Next, initiate a Bluetooth data transfer to the mobile app and make sure that the peak current draw does not exceed the 240 mA.
2. User Feedback Interface: Provides a 3.3V Pulse Width Modulated (PWM) signal at frequencies between 2kHz and 4kHz to drive the piezo buzzer.	• Connect an oscilloscope to the ESP32's PWM output pin designated for the buzzer. • Then, trigger the software routine for an incorrect form alert. • Confirm on the oscilloscope that the signal's peak amplitude is 3.3V and the frequency reads between 2kHz and 4kHz.
3. Wireless Interface (BLE): Must support Bluetooth Low Energy 4.2/5.0 protocols to maintain a stable link with a mobile device.	• Ensure the Smart-Clip is paired with a compatible phone running the mobile application. • Perform a simulated ten to twenty rep set and confirm that all the recorded metrics transmit

Subsystem Requirements	Verification
	successfully to the app without dropping the connection.
4. Non-Volatile Storage: The subsystem must have at least 4MB of memory to store workout logs (rep counts and metrics) in the event of a Bluetooth disconnection.	• Drop the device's Bluetooth connection. • Then, run a script to write a 4MB dummy file of workout logs directly to the ESP32's onboard flash memory. • Disconnect and reconnect the power to the device. • Then read the ESP32 flash memory to confirm the entire 4MB file is retained and uncorrupted.
5. I/O Logic: All digital logic must operate at 3.3V	• Ensure the system is powered on and actively running. • Then, use an oscilloscope to probe the active digital GPIO pins. • Finally, confirm that the logic HIGH voltage level is 3.3V.

Table 3. Central Processing and Control Subsystem Requirements & Verifications.

2.2.4 IMU (6-axis)

A 6-axis IMU (Inertial Measurement Unit) is the sensor inside a Smart-Clip that measures movement. In this case, it has a 3-axis accelerometer and a 3-axis gyroscope. The accelerometer measures linear acceleration, and the gyroscope measures rotational movement. As a person lifts weights with the device, the IMU collects data that is used to identify how many repetitions are being performed and to measure instability during the workout. The IMU will communicate this information to an ESP32 (Microcontroller). The ESP32 will then compute whether or not the person is performing his/her exercise in the correct form.

Subsystem Requirements	Verification
1. Data Interface: Connects to the ESP32 through a Serial Data (SDA) and Serial Clock (SCL) lines using 3.3V logic levels.	• Ensure the IMU is wired to the ESP32 and actively polling data. • Then, attach an oscilloscope to the SDA and SCL traces on the PCB. • Confirm that valid I2C data packets are being transmitted and that the peak voltage of the clock and data pulses is 3.3V.
2. Power Interface: Must be supplied with a stable 3.3V	• Ensure the system is powered under normal load.

	• Then, place multimeter probes directly on the VDD and GND pins of the IMU sensor. • Confirm that the supply voltage holds steady at 3.3V.
3. Physical Interface: Must be rigidly mounted to the Smart-Clip PCB, which in turn is clamped to the barbell, to ensure that vibration and motion are transferred directly.	• Make sure that the IMU is mounted to the PCB. • Apply a force to the barbell. • Confirm that the mounted smart-clip component has not shifted and check data logs for the IMU readings which should show the motion of the barbell.
4. Minimum Sampling Rate: The sensor must be configured to an output data rate of at least 100 Hz to capture high frequency "shakes" common in muscle fatigue.	• Ensure the ESP32 is connected to a device (computer). • Then, utilize a script to record the timestamp every time it receives new data from the IMU. • Let the system run for 10 seconds and review the timestamps and confirm at least 1000 distinct data points in the window.

Table 4. IMU (6-axis) Requirements & Verifications.

2.4 Tolerance Analysis

The most critical feature of the Smart-Clip is its ability to detect wobbles greater than 15 degrees while avoiding false alerts during clean repetitions. Since wobble detection depends entirely on the IMU's angle measurement, we must show that sensor tolerances will not prevent the system from meeting this requirement.

The 6-axis IMU includes a 3-axis accelerometer and a 3-axis gyroscope. According to typical manufacturer specifications for low-cost MEMS IMUs, the accelerometer bias error is approximately +/-0.05g. Because tilt angle is calculated using gravity (1g) as a reference, this bias directly affects angle accuracy.

The tilt angle is estimated using the accelerometer ratio method:

$$\theta = \tan^{-1}(ax / az)$$

If gravity is 1g and the bias error is +/-0.05g, the worst-case ratio error is 0.05. Taking the inverse tangent of 0.05 gives an approximate maximum angle error of about +/-2.86 degrees, which we round to +/-3 degrees.

This means that when the system measures a 15-degree wobble, the true angle could realistically be between about 12 degrees and 18 degrees in the worst case.However, during proper and controlled bicep curls, normal motion is typically less than 5 degrees. Even if we add the maximum +/-3-degree sensor error, the measured angle would still be around 8 degrees, which is well below the 15-degree wobble threshold.

Because the possible measurement error (about 3 degrees) is much smaller than our detection limit (15 degrees), there is a clear margin between acceptable motion and excessive wobble. Therefore, sensor tolerances should not cause frequent false alerts, and the Smart-Clip should still detect improper form in at least 90 percent of trials as required.

From this analysis, we conclude that IMU measurement tolerance is not the limiting factor in our design, and the system can meet its wobble detection specification even under worst-case sensor error conditions.

3. Cost and Schedule

3.1 Cost Analysis

Part	Manufacturer	Retail Cost ($)	Number of items Purchased	Actual Cost ($)
HIGH PRECISION 6-AXIS MEMS MOTIO	TDK InvenSense	$4.29	4	$17.16
BUZZER PIEZO 3V 12.2MM TH	TDK Corporation	$0.448	10	$4.48
IC REG LINEAR 3.3V 600MA SOT-25	Diodes Incorporated	$0.22	5	$1.10
YMCRLUX 1"x32ft Hook and Loop Straps with 50 Metal Buckles Adjustable Fastening Cable Straps Cut-to-Length Cinch Strap Reusable Nylon Securing Cord Ties for Organizer or Storage 1 inch Wide Black	YMCRLUX	$12.98	1	$12.98
TRYMAG Small Strong 6 Different Sizes 255Pcs Rare Earth Magnets for Crafts Heavy Duty Neodymium Round Refrigerator Magnets for Whiteboard Home Kitchen Office School	TRYMAG	$12.59	1	$12.59

HiLetgo 3pcs GY-521 MPU-6050 MPU6050 3 Axis Accelerometer Gyroscope Module 6 DOF 6-axis Accelerometer Gyroscope Sensor Module 16 Bit AD Converter Data Output IIC I2C for Arduino	HiLetgo	$10.99	1	$10.99
Passive Buzzer Module 5 Pcs 3. 3-5V Passive Low Level Buzzer Frequency Controllable Sound Module with 3 Pin Control for Electronic Projects	Naroote	$7.18	1	$7.18
Qimoo 503450 3.7V Lipo Battery 1000mAh 503450 Rechargeable Lithium Polymer Battery Pack with JST PH2.0mm Connector for Electronic Device	Qimoo	$7.59	2	$15.18
HiLetgo 3pcs TP4056 Type-c USB 5V 1A 18650 Lithium Battery Charger Module Charging Board with Dual Protection Functions	HiLetgo	$5.99	1	$5.99
ESP-WROOM-32 ESP32 ESP-32S Development Board 2.4GHz Dual-Mode WiFi + Bluetooth Dual Cores Microcontroller Processor Integrated with Antenna RF AMP Filter AP STA Compatible with Arduino IDE (3PCS)	AITRIP	$16.59	1	$16.59
Total		**$78.868**		**$104.24**

The total cost for all parts listed above is $104.24 before shipping and tax. Assuming a 5% shipping cost, this adds an additional $5.21, bringing the subtotal to $109.45. Additionally, applying a 10% sales tax on the original parts cost adds $10.42. Therefore, the total material cost including shipping and tax is $119.87. For labor, we assume a rate of $40 per hour. If each team member works 2.5 hours per week over 60 weeks, the total labor cost per team member is $6,000. With three team members, the total labor cost amounts to $18,000. When combining both material and labor costs, the total estimated project cost is $18,119.87.

3.2 Schedule

Week	Task	Team Members (responsible)
1	Complete Project Proposal and block diagram	All
2	Design PCB layout, Order parts and materials, and Complete Design document	All

3	Assemble initial electronics (microcontroller, IMU, buzzer)	Bhanuprakash & Sree
4	Develop firmware for IMU data acquisition and filtering	Bhanuprakash & Sree
5	Implement form analysis algorithm and feedback logic	Sree & Ishank
6	Integrate BLE communication with companion app	Sree & Ishank
7	Assemble mechanical clip and attach electronics	Bhanuprakash & Ishank
8	Test integrated system: sensor accuracy, feedback latency, BLE	All
9	Refine the prototype, fix bugs, and run final validation tests.	All
10	Prepare project documentation, visuals, and demo	All

4. Engineering Standards, Ethics, and Safety Considerations

4.1 Societal Impact

Our project makes a positive contribution to public health and safety by helping users maintain proper form while lifting weights. Poor form during free weight exercises is one of the main causes of gym-related injuries, and our Smart Clip provides real-time feedback that can reduce that risk. Economically, it offers a lower-cost alternative to hiring a personal trainer, making safe training more accessible to more people. Socially, it supports individuals who may feel uncomfortable asking for help in gyms, especially beginners. From an environmental standpoint, the device is small, rechargeable, and designed for long-term use to reduce battery waste. Overall, the goal is to improve safety, accessibility, and confidence in strength training both locally and globally.

4.2 Engineering Standards

Several engineering standards apply to our project. Since the device uses Bluetooth communication and embedded electronics, IEEE standards related to wireless communication and signal integrity are relevant. If this product were commercialized, UL safety standards for consumer electronic devices would also apply, especially regarding battery safety and electrical protection. Because we are collecting and transmitting user data, basic data security practices consistent with ACM computing guidelines would also be important. These standards ensure that the system is reliable, safe, and professionally designed

4.3 Ethics and Safety Considerations

The IEEE and ACM Codes of Ethics emphasize prioritizing public safety, being honest about system limitations, and protecting user data. For our project, this means we must clearly communicate that the Smart Clip is an assistive tool and not a certified medical or professional training device. We also have a responsibility to ensure the device does not give misleading feedback that could cause harm. Data collected through the app should be securely transmitted and not shared without user consent. Following course ethics guidelines, we must test thoroughly, report results honestly and not exaggerate the device's accuracy or performance. Ethical concerns include user overreliance on the device and potential privacy risks if workout data is mishandled.

4.4 Electrical and Mechanical Safety Concerns

Electrically, the main safety concern involves the rechargeable battery and ensuring it does not overheat, short-circuit, or become damaged during use. We must follow course lab safety guidelines when handling batteries and embedded systems, including proper insulation and safe charging procedures. Mechanically, the clip must be secure, so it does not detach during lifting, which could distract the user or cause injury. Sharp edges, exposed wiring, or loose components must be avoided. Since the device is attached to moving gym equipment, durability and secure fastening are critical safety considerations. Any new risks identified since our proposal include the possibility of battery damage from repeated impacts if the weight is dropped.

4.5 Procedures to Mitigate Safety Concerns

To mitigate battery risks, we will use a protected lithium battery with built-in overcharge and short-circuit protection and follow safe charging procedures in the lab. All electrical connections will be insulated, and the PCB will be enclosed in a protective casing to prevent accidental contact. Mechanically, we will design the clip with a high-friction inner lining and secure locking mechanism to prevent rotation or detachment. Before demonstrations, we will test the device under repeated lifting conditions to ensure stability. We will also create a short safety document outlining proper use, charging instructions, and limitations of the device. These design decisions help ensure the Smart Clip protects both users during workouts and developers during testing and assembly.

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