

FORMA: THE SMART-CLIP

By

Sree Akkina

Ishank Pujari

Bhanuprakash Kunam

Final Report for ECE 445, Senior Design, Spring 2026

TA: Po-Jen Ko

6 May 2026

Project No. 82

Abstract

The Smart-Clip is a compact device that attaches to a dumbbell or barbell to monitor lifting form in real time. It uses a 6-axis inertial measurement unit (IMU) and an ESP32 microcontroller to track motion and detect wobble and unsafe accelerations during exercises. During each repetition, the device provides immediate audio feedback via a buzzer, indicating whether the user's form was correct or incorrect.

Upon completion of a workout, the Smart-Clip transmits the rep count and wobble metrics through Bluetooth Low Energy (BLE) to a mobile application for review after the set is completed. Testing demonstrated that the device can accurately detect excessive wobble, deliver feedback within acceptable latency limits, and maintain reliable communication in close range. Additionally, results confirmed that the Smart-Clip meets operational requirements for both power efficiency and mechanical stability.

Contents

- 1. Introduction 1
 - 1.1 Solution 1
 - 1.2 Visual Aid..... 1
- 2 Design..... 2
 - 2.1 Introduction 2
 - 2.2 Design Procedure 3
 - 2.2.1 Design Procedure 3
 - 2.2.2 Physical Component Design 4
 - 2.3 Design Details..... 6
 - 2.3.1 Power Management System 6
 - 2.3.2 Central Processing and User Feedback System 7
 - 2.3.3 Motion Sensing Subsystem 8
 - 2.4.1 Mobile Application..... 8
- 3. Design Verification 9
 - 3.1 Power Management Subsystem 9
 - 3.2 Control Subsystem 9
 - 3.3 IMU Subsystem 10
 - 3.4 Mobile Application..... 10
- 4. Costs 11
 - 4.1 Parts 11
 - 4.2 Labor 12
- 5. Conclusion..... 13
 - 5.1 Accomplishments..... 13
 - 5.2 Uncertainties..... 13
 - 5.3 Ethical considerations 13
 - 5.4 Future work..... 13
- 6. References 14
- Appendix A..... 15

1. Introduction

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.

1.1 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.

1.2 Visual Aid

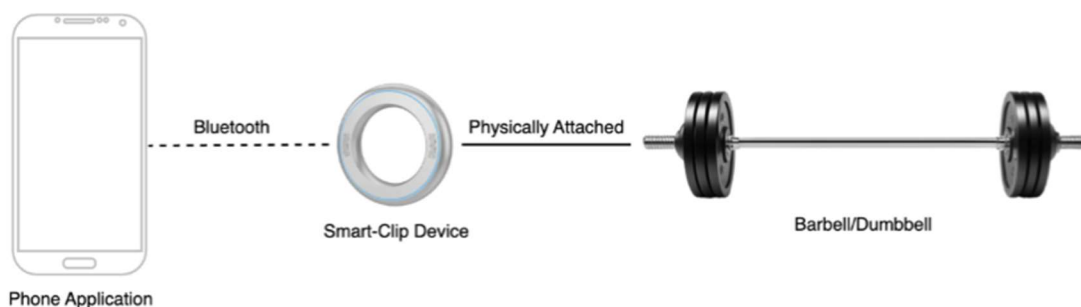


Figure 1. High level Visual Aid.

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.

2 Design

2.1 Introduction

The Smart-Clip architecture is divided into two primary subsystems: the Smart-Clip Device and the Mobile Application System, as detailed in Figure 2.

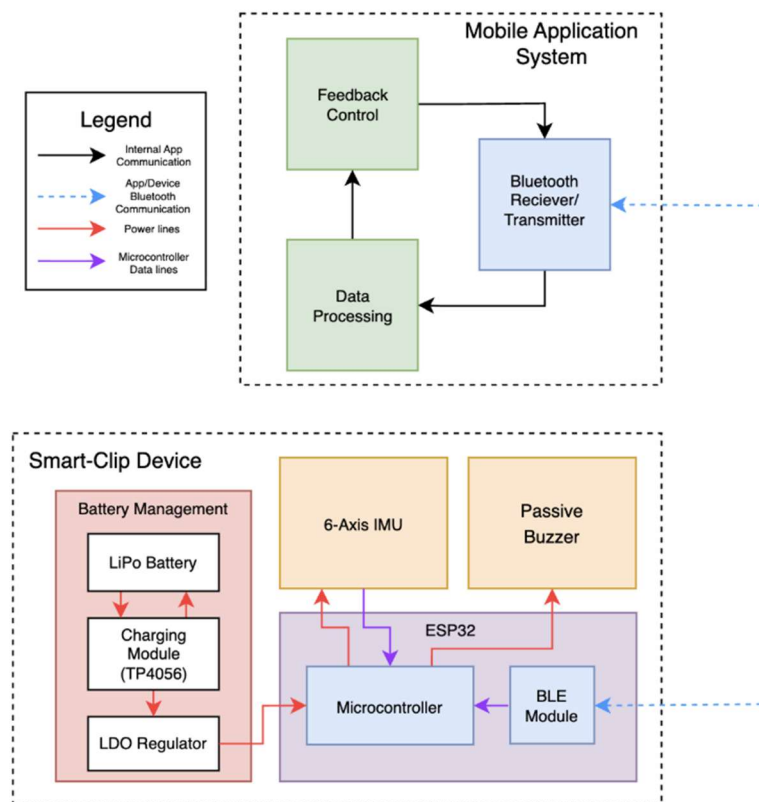


Figure 2. Block Diagram

The physical device is powered by a dedicated Battery Management block which contains a 3.7V LiPo battery, a TP4056 charging module, and a 3.3V LDO regulator. The central processing and control logic is driven by an ESP32 microcontroller, which directly interfaces with a 6-axis IMU for motion data

acquisition. The ESP32 also drives a passive buzzer using a PWM signal for audio feedback and utilizes its BLE module for wireless data transmission. The Mobile Application System acts as the receiving end handling the intake of BLE packets and displaying user performance metrics.

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.

2.2 Design Procedure

2.2.1 Design Procedure

1. Central Processing Subsystem

The core processing requirement was a microcontroller capable of handling high frequency sensor polling while simultaneously maintaining a Bluetooth Low Energy (BLE) connection to the mobile application.

- Alternatives Considered: We evaluated the nRF5284, but it lacks the dual core processing power needed for complex, real-time calculations.
- Chosen Design: The ESP32-S3-WROOM-1 was selected. Its dual core architecture allows one core to manage the BLE connection while the other handles the I2C sensor polling. Additionally, the chip has extensive documentation which would simplify debugging and integration if needed.

2. Power Management Subsystem

The power system must safely charge a 1000mAh LiPo battery and provide a clean, stable 3.3V rail for the processor and sensitive IMUs.

- Alternatives Considered for Voltage Regulation: We initially thought of using a simple voltage divider circuit as a potential method to step down the battery voltage to 3.3V. While a voltage divider is easy to implement and only requires two resistors, it is unsuitable because the output voltage is highly dependent on the load resistance. The ESP32-S3's dynamic current draw would cause the supply voltage to fluctuate wildly leading to system instability.

- Chosen Design: We implemented a Low Dropout (LDO) linear regulator, specifically the AP2112K-3.3. An LDO is desirable because it provides a fixed, stable output voltage regardless of the varying load current.
- Alternatives Considered for Battery Charging IC: During the initial design phase, we evaluated the use of the MAX1555, and rejected it due to its fixed charging current which is capped at 280mA. For a 1000mAh battery, this would result in a charge time exceeding four hours which was not ideal.
- Chosen Design: The TP4056 is available in an ESOP-8 package. This allowed for reliable soldering by hand. The TP4056 has dedicated pins that allowed us to drive status LEDs directly without wasting ESP32 GPIO pins or requiring additional logic.
- Design Equations: To ensure the battery is charged at a safe rate, the programming resistor was selected to target 500mA which was the recommended charge rate according to the datasheet.

$$R_{PROG} = 1200/I_{BAT}$$

3. Motion Sensing Subsystem (IMU)

- Alternatives Considered: We evaluated using the SPI protocol for faster data transfer rates compared to I2C. However, SPI requires four dedicated signal lines per sensor, which would complicate the PCB routing and consume extra GPIO pins.
- Chosen Design: I2C

4. User Feedback Subsystem

The device requires an audio alert system to notify the user of incorrect lifting form in real-time without requiring them to check their phone.

- Alternatives Considered: An active buzzer was considered for its simplicity. However, active buzzers are limited to a single, monotone frequency.
- Chosen Design: A passive piezoelectric buzzer driven by an NMBT2222A NPN transistor was selected. This allows the ESP32-S3 to use Pulse Width Modulation (PWM) to generate varied audio frequencies. The transistor handles the 240mA transient spikes, isolating the ESP32's GPIO pins from damage.

2.2.2 Physical Component 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 component 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 be securely strapped (via Velcro) onto standard barbells without adding significant weight or bulk.

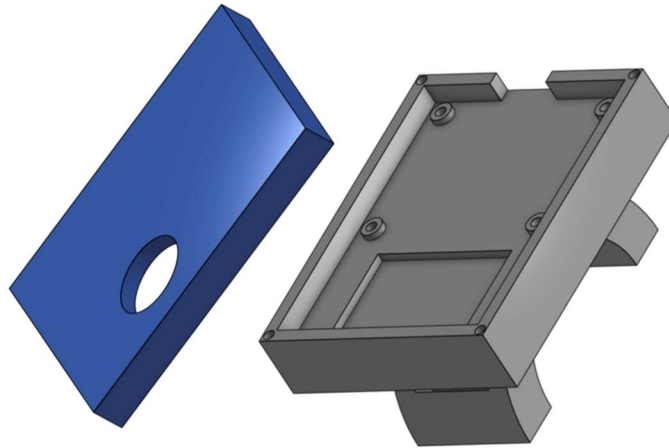


Figure 3. CAD models of the PCB housing.

This PCB housing structure also has the buzzer hole to allow for the buzzer alerts to be heard by the user. In addition, the hole also serves as a passthrough for the button the user interacts with to start and stop each repetition. The PCB housing structure is designed cleverly to allow for the PCB and battery module to be accessible on the top. The lid of the structure securely mounts on with magnets, and the whole clip structure can be mounted on the end of the barbell as is shown in the following figure.

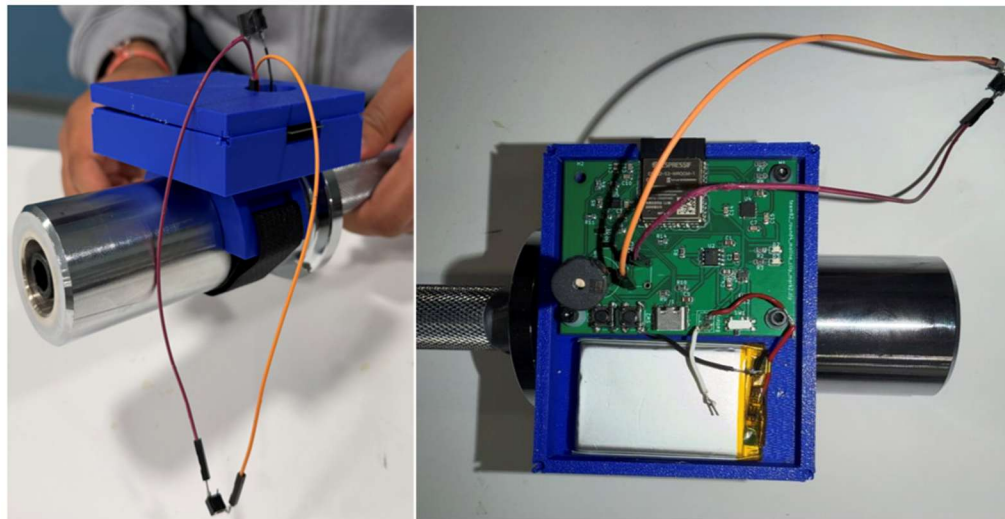


Figure 4. Fully assembled Smart-Clip mounted on barbell.

2.3 Design Details

2.3.1 Power Management System

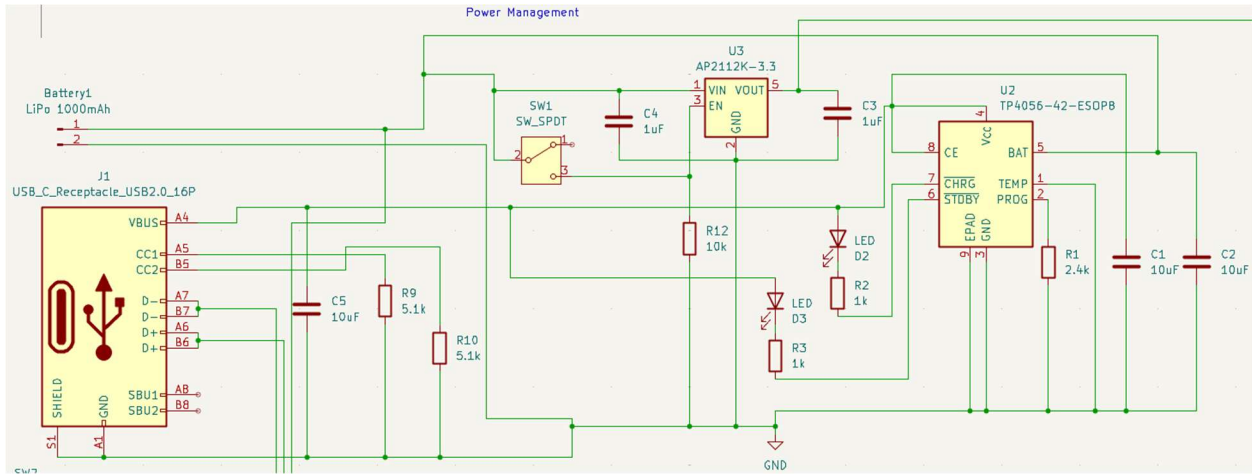


Figure 5. PCB Schematic for the Power Management System.

The power management subsystem, illustrated in Figure 5, is designed to regulate input from a USB-C source to charge a 1000 mAh LiPo battery and provide a stable 3.3V power rail for the other systems.

- **USB Interface and Input Protection:** A 16-pin USB-C receptacle (J1) serves as the primary 5V DC power input. To ensure compatibility with USB-C power delivery ports, two 5.1kΩ pull down resistors are connected to the CC1 and CC2 lines. A 10µF ceramic capacitor is placed at the VBUS input to filter high-frequency noise from the power source.
- **Battery Charging Circuit:** A TP4056 linear charging IC (U2) is used to manage the LiPo battery's constant-current/constant-voltage (CC/CV) charging cycle. The programming resistor is set to 2.4kΩ to establish a charging current of 500 mA. This value was determined using the following equation:

$$R_{PROG} = \frac{1200}{R_{PROG}} = \frac{1200}{2400\Omega} = 0.5A$$

Dual 10µF capacitors provide decoupling on the battery power rail to stabilize the voltage during high current transitions. Visual status is provided by two LEDs (D2 and D3) connected to the CHRG and STDBY pins with 1kΩ current limiting resistors.

- **Voltage Regulation:** To provide the 3.3V required by the ESP32 and IMU sensors, an AP2112K-3.3 Low Dropout (LDO) regulator (U3) is used. Per datasheet recommendations for stability, 1µF ceramic decoupling capacitors were placed at the input and output pins. A SPDT slide switch (SW1) is positioned between the battery rail and the LDO's input to turn off the power to the system while maintaining the battery's connection to the charging module.

2.3.2 Central Processing and User Feedback System

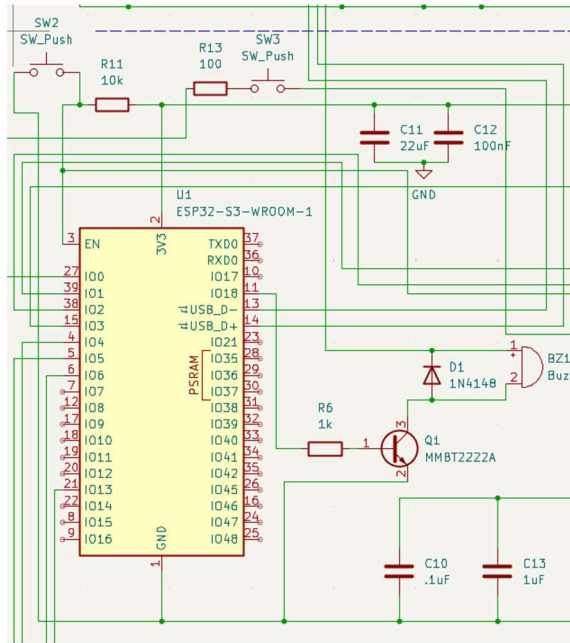


Figure 6. PCB Schematic for the Central Processing and User Feedback Subsystem.

The central processing and user feedback subsystems, illustrated in Figure 6, integrate the logic control and real-time auditory feedback capabilities of the Smart-Clip.

- **Central Processing:** The subsystem is centered around the ESP32-S3-WROOM-1 (U1), a dual-core microcontroller module with integrated BLE capabilities. The module is powered with the 3.3V rail from the power management subsystem. To ensure power stability and mitigate high frequency switching noise, a 22uF capacitor and a 100nF capacitor are placed in parallel near the 3.3V input. The MCU utilizes pins 13 and 14 for USB communication to facilitate firmware updates. SW2 is tied to the EN pin with a 10kΩ resistor to provide a hard reset function. SW3 is connected to GPIO IO0 via a 100Ω resistor to provide a boot function.
- **User Feedback Interface:** Real time auditory alerts are generated using a passive piezoelectric buzzer (BZ1). Because the ESP32 GPIO pins cannot safely drive the current required by the buzzer, an MMBT2222A NPN transistor (Q1) is used. The ESP32 controls the buzzer via a Pulse Width Modulated (PWM) signal.
- **Base Current Control:** A 1kΩ base resistor limits the current drawn from the GPIO pin. The base current is calculated using the minimum base-emitter saturation voltage of 0.6V at $I_C = 150mA$

$$I_B = \frac{V_{GPIO} - V_{BE(sat)}}{R_6} = \frac{3.3V - 0.6V}{1000\Omega} = 2.7mA$$

- **Transient Protection:** A 1N4148 diode (D1) is placed in parallel with the buzzer load. This protects the MMBT2222A from inductive voltage spikes.

2.3.3 Motion Sensing Subsystem

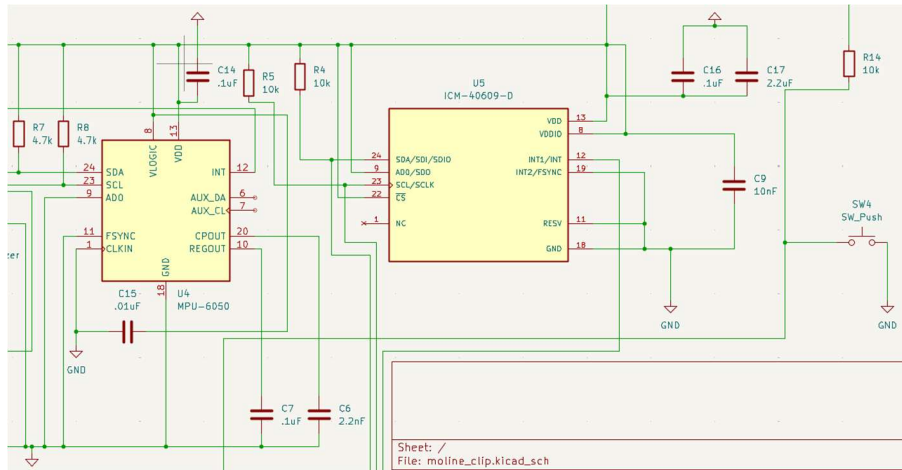


Figure 7. PCB Schematic for the Motion Sensing Subsystem.

The motion sensing subsystem, shown in Figure 7, utilizes two separate I2C buses to interface the sensor array. Each IMU is wired to independent GPIO pins on the ESP32. This design choice is desirable to maximize data throughput and eliminate bus contention during simultaneous high frequency polling.

- MPU-6050 Configuration (U4): The IC is supplied with 3.3V at the VDD and VLOGIC pins, supported by a 0.1uF bypass capacitor. The REGOUT is stabilized with a 10nF capacitor, which is critical for maintaining the stability of the internal sensor logic. The INT pin is connected to a dedicated MCU interrupt to signal when a new data packet is ready for processing. The bus utilizes 4.7kΩ pull up resistors to maintain signal integrity.
- ICM-40609-D Configuration (U5): To enable I2C communication, the Chip Select is tied high to VDDIO. The AD0/SDO pin (pin 9) is tied to the 3.3V rail, setting the I2C target address to 0x69. The RESV pin (pin 11) is correctly decoupled with a 10nF capacitor to ground, while VDD and VDDIO are filtered by two capacitors in parallel to handle transient current draws during sensor activation. The bus utilizes 10kΩ pull up resistors to maintain signal integrity.

2.4.1 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 8, the mobile application receives real-time IMU data from the Smart-Clip. The app also stores all the workout logs in the history page where the user can go in and check each set they have completed and how many good/bad reps they had in each one.

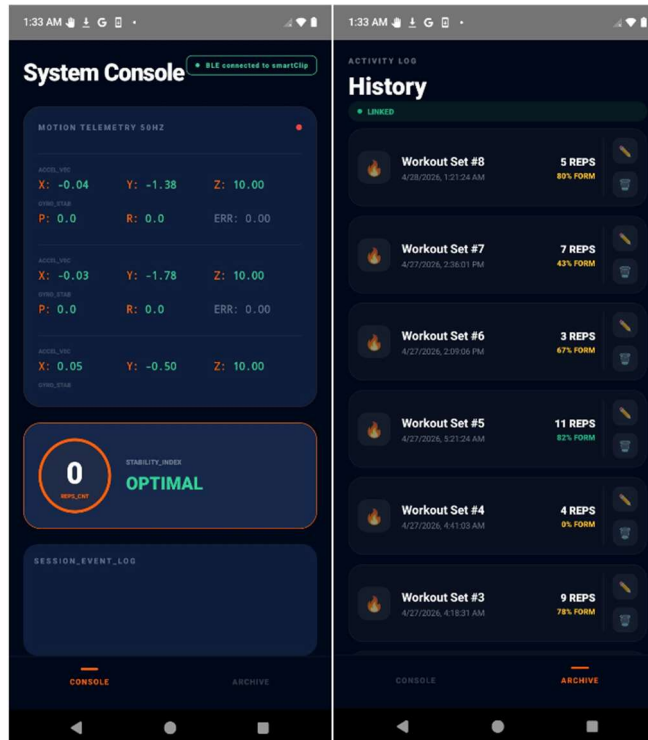


Figure 8. Android App with console and history/archive pages.

3. Design Verification

3.1 Power Management Subsystem

Subsystem Requirement	Verification	Verification status (Y or N)
<ul style="list-style-type: none"> Battery Charging Interface: Provides 4.2V (max) for charging and accepts 3.0V to 4.2V for discharging. 	<ul style="list-style-type: none"> Ensure battery is charging. Observe if the device operates under the correct voltage range. 	Y
<ul style="list-style-type: none"> Regulated Output Interface: Supplies a continuous 3.3V to the ESP32 with a maximum current capacity of 600mA. 	<ul style="list-style-type: none"> Confirm with a multimeter that the output voltage is at a stable 3.3V across the current range. 	Y

3.2 Control Subsystem

Subsystem Requirement	Verification	Verification status (Y or N)

<ul style="list-style-type: none"> Power Interface: Accepts a regulated 3.3V input and must operate within a current draw range of 80mA (idle) to 400mA (peak BLE transmission). 	<ul style="list-style-type: none"> Verify through datasheet 	Y
<ul style="list-style-type: none"> Wireless Interface (BLE): Must support Bluetooth Low Energy 4.2/5.0 protocols to maintain a stable link with a mobile device. 	<ul style="list-style-type: none"> Perform a simulated ten to twenty reps set and confirm that all the recorded metrics transmit successfully to the app without dropping the connection. 	Y

3.3 IMU Subsystem

Subsystem Requirement	Verification	Verification status (Y or N)
<ul style="list-style-type: none"> Minimum Sampling Rate: The sensor must be configured to an output data rate of at least 50 Hz to capture high frequency “shakes” common in muscle fatigue. 	<ul style="list-style-type: none"> 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 500 distinct data points in the window. 	Y

3.4 Mobile Application

Subsystem Requirement	Verification	Verification status (Y or N)
<ul style="list-style-type: none"> The mobile application must receive data from the Smart-Clip via Bluetooth Low Energy (BLE) and display it in real time. 	<ul style="list-style-type: none"> Connect Smart-Clip via BLE and perform 10 repetitions Confirm live IMU data updates continuously during each rep showing X, Y, and Z accelerometer values Confirm 10 rep entries are saved as JavaScript objects in AsyncStorage with no dropped packets 	Y
<ul style="list-style-type: none"> The application must display repetition counts and stability metrics in real time by processing incoming IMU data received over BLE. 	<ul style="list-style-type: none"> Perform 10 reps where the final three have intentional lateral wobble exceeding 15 degrees Confirm rep counter and stability index update after each rep Confirm first seven reps saved as PASS and final three saved as FAIL in AsyncStorage 	Y

4. Costs

4.1 Parts

Table 1. Parts Cost

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	Narooto	\$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

4.2 Labor

For labor, we assume a rate of \$40 per hour. If each team member works 2.5 hours per week over 14 weeks, the total labor cost per team member is \$3,500. With three team members, the total labor cost amounts to \$10,500. When combining both material and labor costs, the total estimated project cost is \$10,619.87.

5. Conclusion

5.1 Accomplishments

We successfully built a working prototype of the Smart-Clip that met all of our core design goals. The device clips onto a barbell, detects repetitions in real time, grades form against a calibrated template, and alerts the user through the buzzer when form breaks down. The custom PCB integrated all subsystems cleanly, the 3D-printed housing fit securely on the barbell with no vibration issues, and the Android app connected automatically over BLE and logged every rep correctly. All four subsystems passed their verification requirements.

5.2 Uncertainties

The biggest uncertainty in the current design is how well the algorithm generalizes across different users and exercises. Right now, the form template is based on two calibration reps done by the same user with no weight, which works well for bicep curls but may not hold up for heavier loads or different movement patterns. The MPU-6050 also produces noisy raw readings, and the thresholds we tuned may not work as well in a noisier environment like a busy gym with lots of vibration around the device.

5.3 Ethical considerations

The Smart-Clip is a feedback tool, not a medical device. A PASS result from the algorithm only means the rep matched the user's own calibration template; it does not guarantee the movement was safe, especially under heavy load. Following the IEEE Code of Ethics, we have an obligation to be clear about this limitation, so users do not over-rely on the device when learning new lifts or pushing their limits. On the privacy side, all workout data is stored locally on the user's phone, and nothing is transmitted to a cloud server, which protects user data by default.

5.4 Future work

The most useful next step would be extending the algorithm to support more exercises beyond bicep curls and making the thresholds adaptive based on the user's weight and rep speed. On the hardware side, the PCB could be made significantly smaller with a tighter layout, and replacing the module with a bare ESP32-S3 chip would reduce the footprint further. Adding iOS support and optional cloud sync for long-term progress tracking would also make the app much more useful for real users.

6. References

- [1] "A Woman's Guide to Gaining Muscle with Weight Training," ACE Fitness, 14 Feb. 2025. Available: <https://www.acefitness.org/resources/everyone/blog/5502/a-woman-s-guide-to-gaining-muscle-with-weight-training/>
- [2] "Nonfatal Sports- and Recreation-Related Injuries Treated in Emergency Departments — United States, July 2000–June 2001," CDC MMWR. Available: <https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5133a2.htm>. Accessed Feb. 26, 2026.
- [3] "The Evolution Of Fitness Tracking," The Medical Futurist, 23 Sept. 2025. Available: <https://medicalfuturist.com/the-evolution-of-fitness-tracking>
- [4] A. Yurtman and B. Barshan, "Activity Recognition Invariant to Sensor Orientation with Wearable Motion Sensors," *Sensors*, vol. 17, no. 8, p. 1838, 2017. Available: <https://doi.org/10.3390/s17081838>
- [5] A. P. Pereira et al., "Wearable Smartphone-Based Multisensory Feedback System for Torso Posture Correction: Iterative Design and Within-Subjects Study," *JMIR Aging*, vol. 8, no. 1, p. e55455, Jan. 2025. Available: <https://doi.org/10.2196/55455>
- [7] Espressif Systems, *ESP32-S3 Series Datasheet*, Version 1.4, 2023. Available: https://www.espressif.com/sites/default/files/documentation/esp32-s3_datasheet_en.pdf
- [8] Diodes Incorporated, *AP2112 Datasheet*, Revision A, 2019. Available: <https://www.diodes.com/assets/Datasheets/AP2112.pdf>
- [9] Texas Instruments, *TP4056 1A Standalone Linear Li-Ion Battery Charger Datasheet*, 2008.
- [10] N. Romagnoli, "ArduinoBLE," Arduino Library Reference, 2023. Available: <https://www.arduino.cc/reference/en/libraries/arduinoable/>
- [11] I. Tabone, "react-native-ble-manager," NPM Package Registry, 2024. Available: <https://www.npmjs.com/package/react-native-ble-manager>

Appendix A

Unit or Term	Symbol or Abbreviation	Unit or Term	Symbol or Abbreviation
Bluetooth Low Energy	<i>BLE</i>	lithium polymer (battery)	<i>LiPo</i>
constant-current/constant-voltage	<i>CC/CV</i>	low dropout (regulator)	<i>LDO</i>
general-purpose input/output	<i>GPIO</i>	microcontroller unit	<i>MCU</i>
inertial measurement unit	<i>IMU</i>	printed circuit board	<i>PCB</i>
integrated circuit	<i>IC</i>	pulse width modulation	<i>PWM</i>
Inter-Integrated Circuit (protocol)	<i>I2C</i>	Serial Peripheral Interface	<i>SPI</i>
Internet of Things	<i>IoT</i>	universal serial bus	<i>USB</i>