SMART-CLIP DEVICE

By

Sree Akkina

Bhanuprakash Kunam

Ishank Pujari

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TA: Po-Jen Ko

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Abstract

The Smart-Clip is a small device that attaches to a dumbbell or barbell for real-time monitoring of the user's lifting form. It uses a 6-axis inertial measurement unit (IMU) sensor and an ESP32 microcontroller to measure motion and detect wobble and unsafe accelerations that occur while performing exercises. Once a repetition is completed, the Smart-Clip provides the user with audio feedback (via a buzzer) to let them know if their form was either correct or incorrect. After completing a workout, all workout data (rep count and wobble measurements) will be sent via Bluetooth Low Energy (BLE) to a mobile application for review after the session. Testing proved that the Smart-Clip can accurately detect excessive wobble, provide feedback within the appropriate latency limits, and communicate consistently for short distances. Lastly, all testing demonstrated that the Smart-Clip met operational requirements for both power efficiency and mechanical stability. ⍰

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1. Introduction

1.1 Problem

Free weight exercises (dumbbells/barbells) require intense focus, and users often cannot safely look at visual displays while performing complex movements. Additionally, beginners frequently suffer from poor form - such as wobbling or using momentum rather than muscle control - which is difficult to self-diagnose without a personal trainer.

1.2 Solution

This project proposes the Smart-Clip, an IoT attachment for barbells and free weights that utilizes auditory feedback to correct form in real-time. The system aims to use an ESP32 microcontroller and a 6-axis IMU to analyze the lift's stability and trajectory. A piezoelectric buzzer provides sound cues: a clean tone confirms a stable, good-form repetition, while a dissonant alert signals excessive wobble or dangerous acceleration. This allows the user to maintain safe positioning while receiving instant coaching on their technique. All form data is logged to an app via Bluetooth for post-workout analysis.
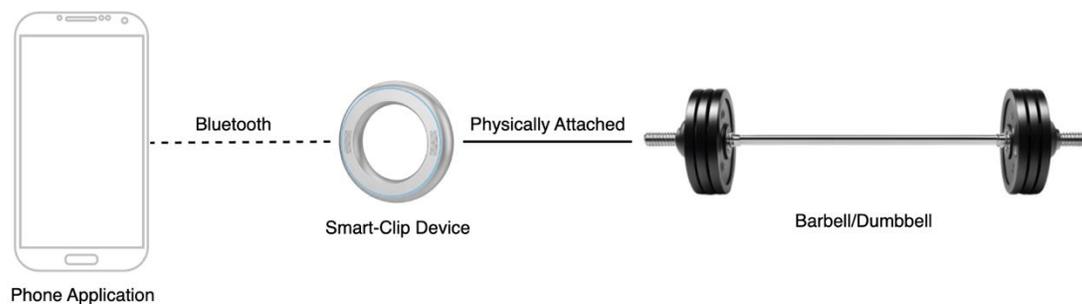
1.3 Visual Aid

Figure 1. High level Visual Aid.

1.4 High-Level Requirements List

1. Repetition Accuracy: Counts bicep curls with = 90% accuracy; detects > 15 degrees wobble in >= 9/10 trials with no false alerts on clean reps.
2. Feedback Latency: Audio feedback occurs within 200 ms of IMU-detected rep completion.
3. Bluetooth Integrity: 100% of completed sets transmit correctly to the app within a 5 m range.
4. Mechanical Stability: Clip rotates less than 10 degrees on the handle during a 10-rep set.
5. Power Efficiency: Operates for at least 1 hour
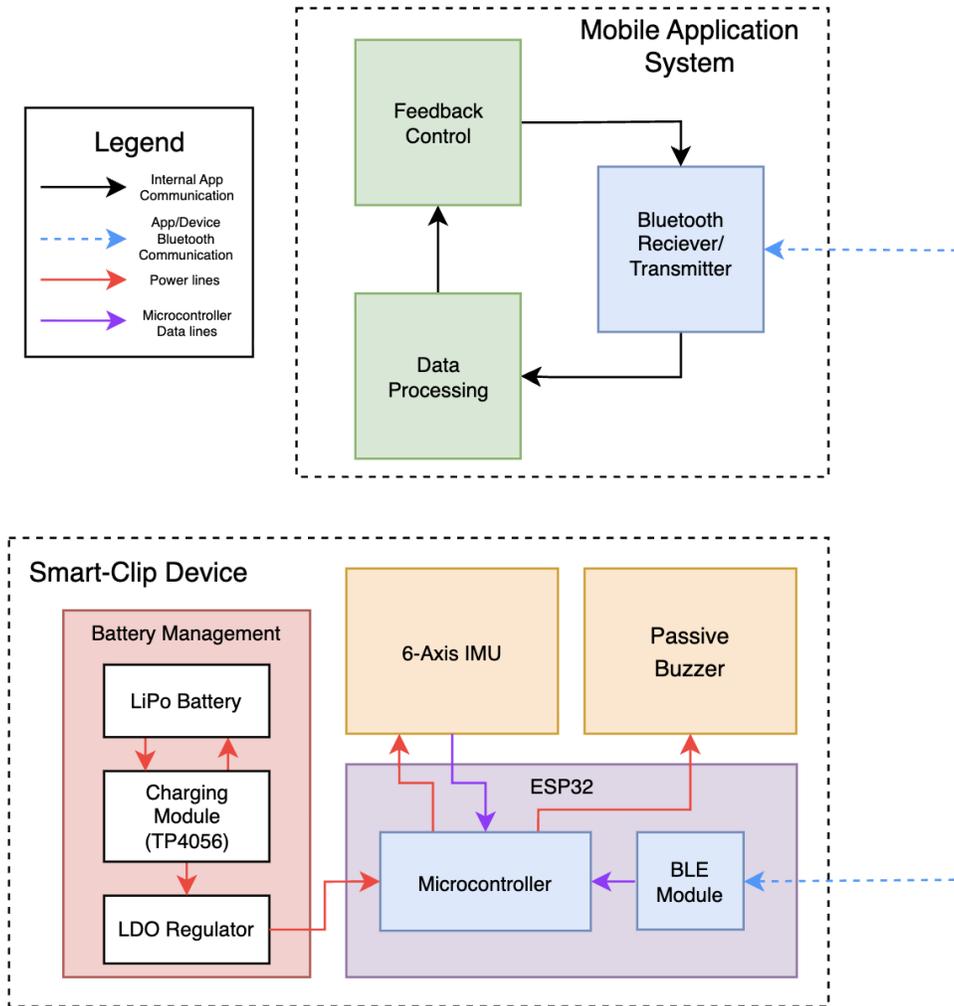
2 Design

2.1Block Diagram

Figure 3. Block Diagram.

2.2 Subsystem Overview

2.2.1   Mobile Application

Users receive workout data from their Smart-Clip through the mobile application. When a user completes a workout, their Smart-Clip uses Bluetooth Low Energy (BLE) to send workout data to the app, including information on the number of repetitions performed and how much the user wobbled during the workout. 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.

2.2.2 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:

1. Input to Battery Charging Interface: Accepts 5V DC at up to 500mA through USB-C for charging
2. Battery Charging Interface: Provides 4.2V (max) for charging and accepts 3.0V to 4.2V for discharging.
3. Regulated Output Interface: Supplies a continuous 3.3V to the ESP32 with a maximum current capacity of 1000mA.

Critical Requirements for Functional Success:

1. Over-Discharge Protection: The subsystem must mechanically disconnect the battery load if the cell voltage drops below 2.4V to prevent chemical degradation.

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:

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).

2. User Feedback Interface: Provides a 3.3V Pulse Width Modulated (PWM) signal at frequencies between 2kHz and 4kHz to drive the piezo buzzer.

3. Wireless Interface (BLE): Must support Bluetooth Low Energy 4.2/5.0 protocols to maintain a stable link with a mobile device at up to 5 meters.

Critical Requirements for Functional Success:

1. 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.

2. I/O Logic: All digital logic must operate at 3.3V

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:

1. Data Interface: Connects to the ESP32 through a Serial Data (SDA) and Serial Clock (SCL) lines using 3.3V logic levels.
2. Power Interface: Must be supplied with a stable 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.

Critical Requirements for Functional Success:

1. 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.

4. Costs

4.1 Parts

Table 1 Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
ESP32 Microcontroller	Espressif Systems	9.39	9.39	9.39
6-Axis IMU	adafruit	19.95	19.95	19.95
TP4056	HiLetgo	2.00	5.99	2.00
3.3V Passive Piezo Buzzer	DIYables	2.25	5.99	2.25
3.7V LiPo Battery 1000mAh	Qimoo	7.39	7.39	7.39
Low Dropout Regulator (AP2112K-3.3)	Diode Incorporated	0.22	1.53	0.22
Total		**40.95**	**42.26**	**40.95**

5. Conclusion

5.1 Project Goals

To develop an attachment to free weights that provides real-time feedback on lifting technique through the use of motion sensing technology and edge processing to sense wobbling and unsafe accelerations associated with free weight exercises. To develop this prototype product with an emphasis on improving the user's safety while complying with established criteria of accuracy, latency, mechanical stability, and energy efficiency.

5.2 Expected Challenges

Several challenges that may arise during the development process such as filtering the IMU Data through appropriate methods to eliminate excess noise, provide low-latency feedback to the user, physically attach the sensors securely to gym equipment, and ensure uninterrupted Bluetooth communication. Power consumption and battery life will also need to be optimized through careful design processes and procedures.

5.3 Ethical and Safety Considerations

Smart-Clip's intention is to provide support to users, not replace the necessity of receiving proper professional training. Correctly designed for mechanical use will help to prevent any accidental disconnection during use. Additionally, all data transmitted from workouts must be handled responsibly in a way that protects users' privacy.

5.4 Future Impact and Development

If successful, the Smart-Clip could provide an accessible tool for improving exercise form and reducing injury risk. Future development may include expanding analytics features, improve hardware design, and explore adaptive feedback methods.

References

Alkes, C. (2025, May 14). Ask the trainer: "What are common signs of incorrect form in strength

training?" *CampusWell*. https://www.campuswell.com/?p=15967