ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Discrete Exercise Repetition & TUT Counter

Team 31

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Introduction

Problem. Accurately tracking exercise repetitions and Time Under Tension (TUT) is essential for optimizing workout performance and ensuring effective training. However, individuals working out at home or without a trainer often struggle to maintain accurate counts of their repetitions and monitor TUT efficiently. Existing solutions, such as expensive gym equipment or smartphone applications, either lack precision or require intrusive setups, such as placing a camera in a gym environment, which may not always be feasible or desirable.

Solution. Our solution is to create a wearable, discrete clip-on device with a custom PCB that uses an MPU6050 accelerometer and gyroscope to detect arm motion during exercises. By processing and analyzing the motion data, the device displays rep counts on an 8-segment display in real time, eliminating the need for camera setups or expensive gym equipment. Furthermore, we intend to tackle the problem of people "cheating" their repetitions by focusing on tracking the user's TUT. A built-in timer tracks the duration of each rep, and once the user's preset target time is reached, a slight vibration alerts them they can now complete the movement. This ensures the user can primarily focus on their exercise without having to constantly watch a clock or screen.
To accommodate different fitness goals, the TUT criteria can be easily adjusted using a dial or potentiometer. In the long term, we see our device being integrated into fitness watches like the Apple Watch/FitBit in a much smaller form factor, which can be achieved by integrating our design into the existing chips in these watches which are manufactured industrially (using TSMC's 4 nm process for the Apple Watch for instance)

Visual Aid. Our approved RFA in its current state features a standalone device as shown below. In the long run, our prototype could be shrunk significantly and integrated into existing smart watches on the market such as the Apple Watch.

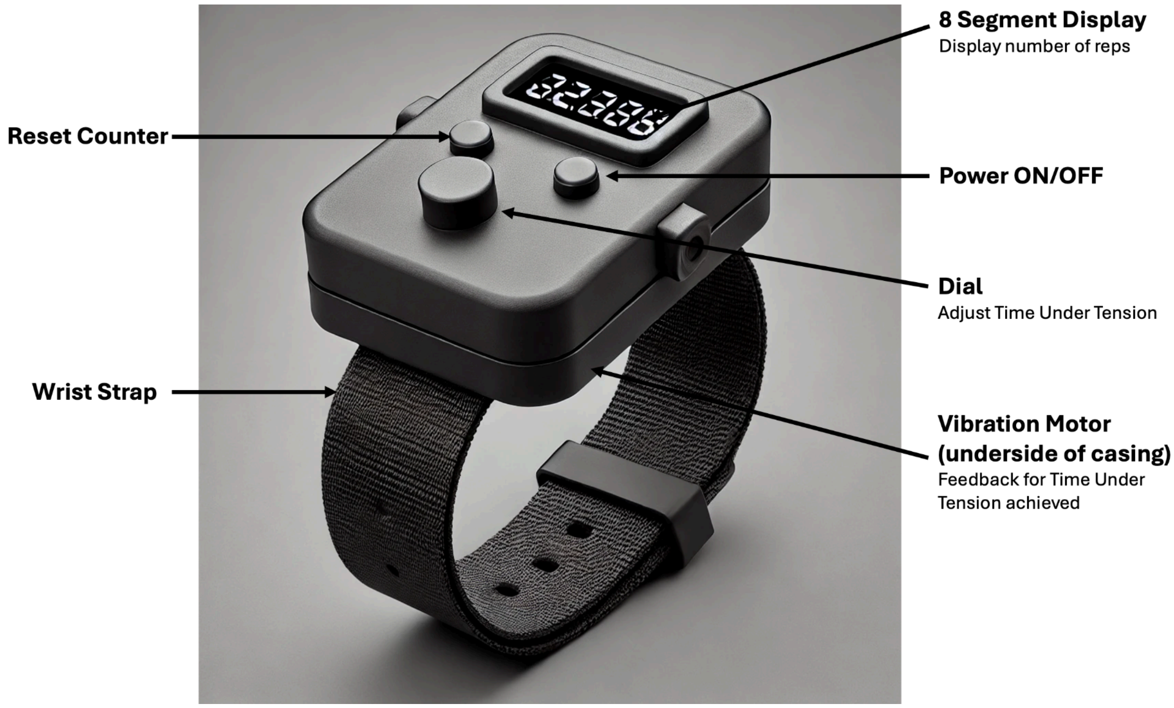

Fig. Sample Visual Aid for Project

High-level requirements list.

1. The user must be able to adjust the Time Under Tension duration between 1 to 10 seconds with 1 second increments using a dial
2. The system accurately detects and counts exercise repetitions with a minimum accuracy of 90%
3. The timer feature shall measure Time Under Tension with an error margin less than ±0.5 seconds per repetition to ensure precise workout tracking

Design

Block Diagram. Block diagram for project:

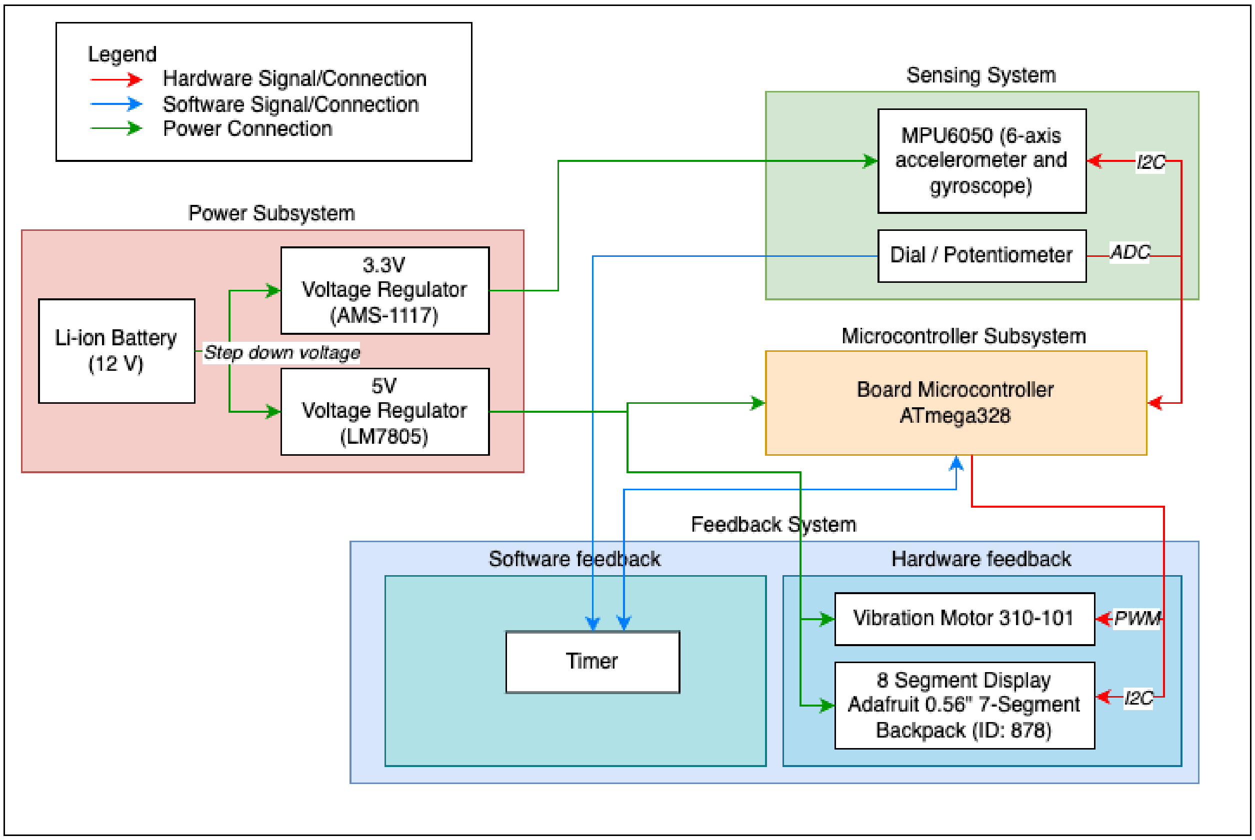

Fig. Project Block Diagram

Subsystem Overview

<u>Subsystem 1: Power Subsystem</u>
The purpose of this subsystem is to provide a stable power supply to all components of the device. It consists of a 12V battery pack which serves as the primary energy source, which feeds into two voltage regulators: the LM7805 for a 5V line and the AMS-1117-3.3V for a 3.3V line. The 5V line powers the microcontroller, display, and vibration motor, while the 3.3V line powers the IMU (MPU6050).

<u>Subsystem 2: Feedback Subsystem</u>
The purpose of this subsystem is to provide real-time feedback to the user through both software and hardware mechanisms. The timer is a software feedback component that is preset by the user via a potentiometer/dial that will indicate a set amount of seconds that the user would like to be under tension during their repetition. Once the preset time is reached, the board's microcontroller will trigger the vibration motor, which will provide a haptic feedback to the user to signal that they can now complete their range of motion. The motor will be controlled using *Pulse-Width Modulation (PWM)*. Furthermore, the 8-segment display will display the current count of repetitions completed, incrementing each time the user completes a repetition. This display will be controlled using the *I2C communication protocol* can be reset to the value 0 by using the "reset" button.

<u>Subsystem 3: Sensing Subsystem</u>
The purpose of the Sensing Subsystem is to track the users arm movement and monitor their TUT during an exercise. This subsystem consists of an MPU6050 accelerometer and gyroscope, which are used to detect changes in motion and orientation to accurately sense the beginning and end of a repetition using *I2C communication protocol*. Additionally, a potentiometer will be used to allow the user to adjust the TUT criteria according to their own fitness goals. We will need to use an *analog to digital converter (ADC)* for the ATmega328 to be able to process analog data from the dial. This subsystem is necessary to gather motion data and send it to the board's microcontroller, which will process the information to accurately count repetitions and track TUT.

<u>Subsystem 4: Microcontroller Subsystem</u>
The purpose of the Microcontroller (AtMEGA328) Subsystem is to be the central processing unit of the device, handling software and hardware data it receives and delivers between each subsystem. It receives motion data from the MPU6050 and analyzes it to detect and count repetitions. Furthermore, it reads the input from the potentiometer to determine the user's expected TUT. Once processed, the microcontroller communicates with the Feedback System to

provide both visual and haptic cures. Finally, the microcontroller also endures power is distributed properly between each of the subsystems.

Subsystem Requirements

Subsystem 1: Power Subsystem Function: Supplies regulated 3.3V and 5V power to all subsystems from a 12V LiPo battery.
Requirement 1: The subsystem must output 3.3V ±0.2V (for the microcontroller and MPU6050) and 5.0V ±0.2V (for the display and motor).
Requirement 2: The battery must support ≥2 hours of continuous operation under peak load (300mA @ 5V, 100mA @ 3.3V).
Requirement 3: Includes overcurrent protection on both output rails. Interfaces: Input: 12V LiPo battery. Outputs: 5V (to microcontroller, MPU6050) and 5V (to display, motor).

Subsystem 2: Feedback Subsystem Function: Provides real-time rep count display, haptic alerts, and user input.
Requirement 1: The 8-segment display must update within 500 ms of a detected rep.
Requirement 2: The vibration motor must activate within 500 ms of TUT completion (10ms response time for the motor driver).
Requirement 3: The display must support 1-digit output (0–F),

Subsystem 3: Sensing Subsystem Function: Captures motion data and TUT settings via the MPU6050 and potentiometer.
Requirement 1: The MPU6050 must sample acceleration/gyro data at ≥ 50Hz.
Requirement 2: The potentiometer must adjust TUT in 1–10s increments using a dial.
Requirement 3: Automatic calibration on startup to zero the sensor when idle for ≥5s.
Interfaces: Inputs: Potentiometer voltage (analog). Outputs: MPU6050 data (I2C), TUT setting (digital).

Tolerance Analysis.

Risk:
The primary risk to achieving the 90% repetition counting accuracy lies in distinguishing valid exercise motion from sensor noise and unintended movements. The MPU6050 accelerometer/gyroscope must reliably detect the start/end of a repetition while rejecting false

positives (e.g., arm adjustments between sets) and noise (e.g., sensor drift, electrical interference).
Feasibility Analysis:

1. **Signal-to-Noise Ratio (SNR) Calculation:**
   - The MPU6050 has a typical accelerometer noise density of **400 µg/√Hz**.
   - With a bandwidth of 50 Hz (sampling rate ≥ 50 Hz), the total noise is:

$$\text{Noise}_{\text{RMS}} = 400\ \mu g \times \sqrt{50Hz} \approx 2.83\ \text{mg (RMS)}$$

   - During a bicep curl, peak acceleration can reach **±2g** (19.6 m/s²). The SNR is:

$$\text{SNR} = 20\log_{10}(2g/2.83mg) \approx 76\ dB$$

   - This high SNR ensures motion signals are distinguishable from noise.
2. **Algorithm Validation:**
   - A moving average filter with a 100 ms window (5 samples at 50 Hz) reduces high-frequency noise.
3. **Calibration Tolerance:**
   - Automatic zeroing during startup (5s idle) compensates for sensor offset.

Ethics and Safety

To maintain an ethical process, our team focused on following IEEE Code of Ethics and ACM Code of Ethics and Professional Conduct. Our group is especially committed to creating the highest quality work by implementing a revision strategy throughout the creation of the project. We will enforce that any work is thoroughly tested and must be revised by at least 1 other group member. This strategy along with weekly meetings with our TA will build a foundation for great quality work. This aligns with ACM Code of Professional Responsibilities 2.1: Strive to achieve high quality in both the processes and products of professional work. Furthermore, in order to continue progressing our project to the highest standards, we will openly receive feedback and criticism and acknowledge our shortcomings as a way to improve our product. This aligns with IEEE Code of Ethics 1.5: to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to properly credit the contributions of others.

Regarding safety, we are committed to following safe practices throughout the duration of the project. By communicating with the Machine Shop, we will ensure that the construction of the device results in a safe product for all users. Furthermore, we will make sure that the subsystems on our PCB are designed to avoid any overheating. Since the device is powered by a Li-Po (Lithium Polymer) battery, specific precautions must be taken to ensure safe operation. Li-Po batteries are sensitive to overcharging, deep discharge, punctures, and extreme temperatures, which can lead to swelling, fire, or explosion. Charging should only be done with a compatible Li-Po charger to avoid voltage mismatches that could degrade battery health. Additionally, users should never puncture, bend, or expose the battery to water to prevent hazardous reactions. When disposing of Li-Po batteries, they must be fully discharged and taken to an authorized battery recycling facility rather than being thrown away in regular trash. The enclosure should also be designed to provide adequate ventilation and protection against impact while ensuring the device remains sweat-resistant (IPX4-rated or higher). Proper safety measures will ensure that the device operates reliably while minimizing risks associated with Li-Po battery usage.