ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Discrete Exercise Repetition & TUT Counter

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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.

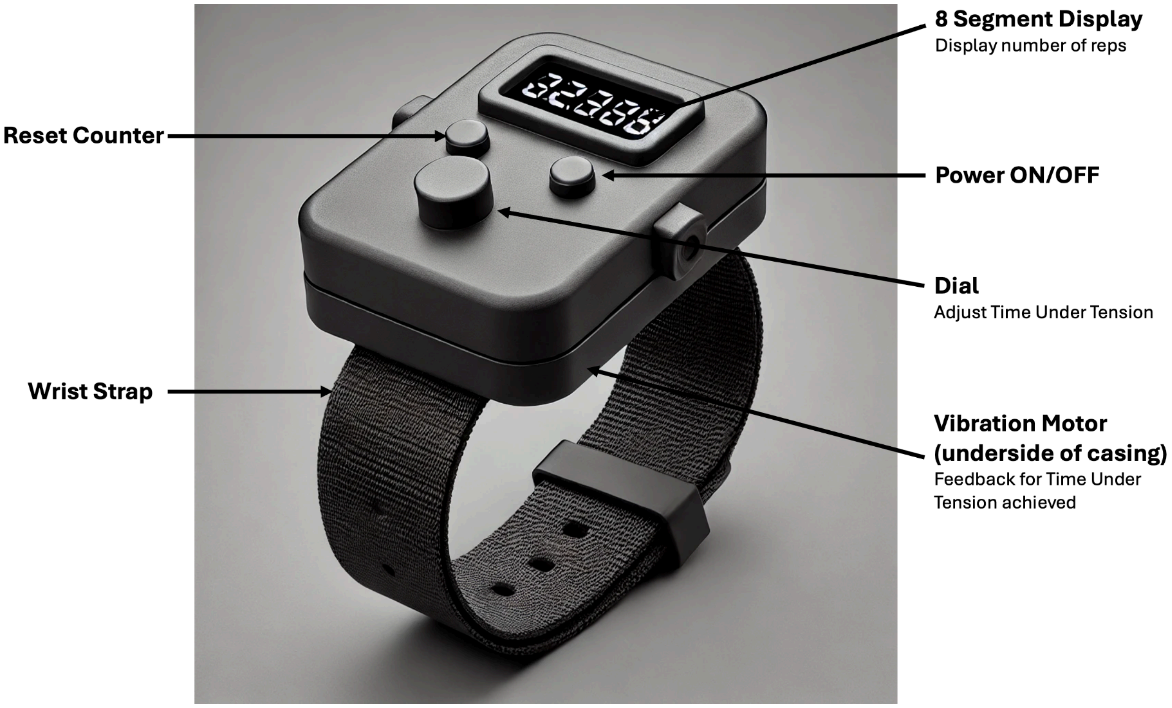

Fig. Sample Visual Aid for Project

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 ±1 second per repetition to ensure precise workout tracking

Design

Block Diagram. Our block diagram consists of four subsystems: Power, Sensing, Feedback, and Microcontroller. The Power Subsystem converts a 12V Li-ion battery into 5V and 3.3V using a Buck Converter and Linear Regulator to power the other core components of the design. The sensing subsystem consists of an MPU6050 (connected via I2C) and a Potentiometer (connected via ADC) which are used to gather exercise motion data and the user's expected Time Under Tension data. The Feedback Subsystem consists of a software based timer, as well as hardware feedback through a Vibration Motor and 7-Segment Display. Finally, the Microcontroller Subsystem revolves around the ATMega328 which receives sensor data as inputs and manages outputs.

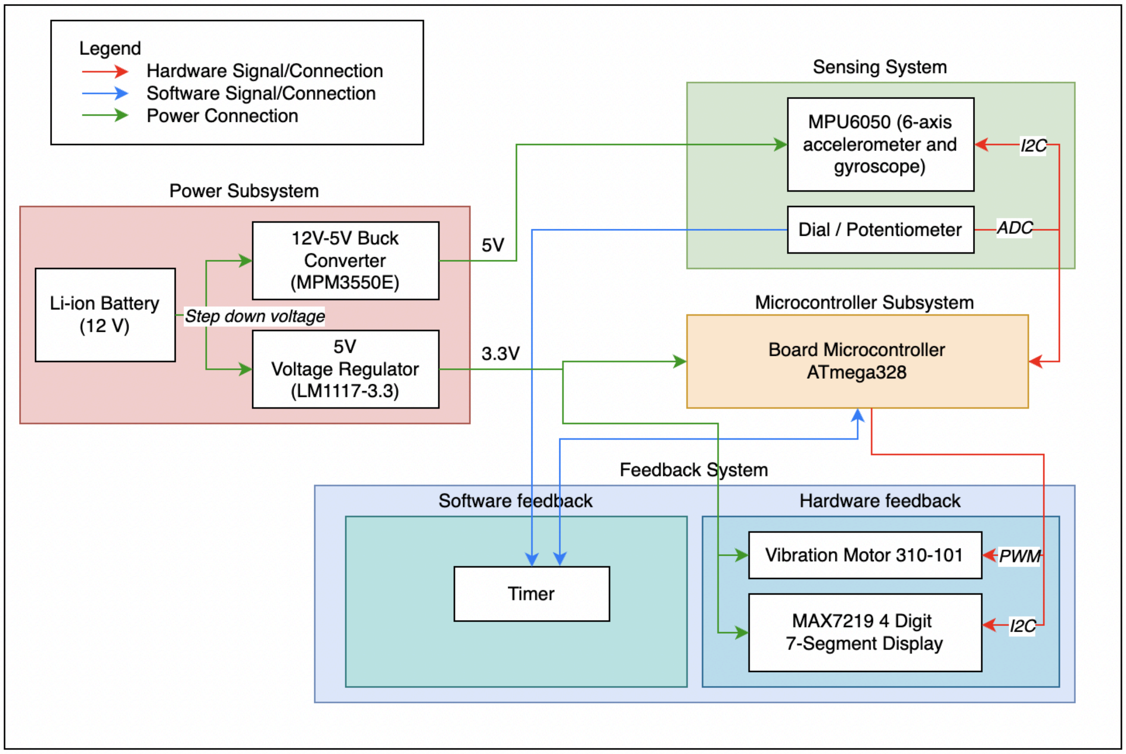

Fig. Project Block Diagram

Physical Design. Our design mimics a watch-like device. It has a compact rectangular box on top, which houses our PCB. A digit, 7-segment display is placed at the top of the box, to display the repetition count. Beneath the display, there exists a small button used to reset the repetition counter, as well as a larger dial that allows the user to adjust the time under tension. Underneath the rectangular case, there is a small protruding vibration motor positioned to provide haptic feedback to the user. Finally, the entire enclosure is secured to the wrist using an adjustable woven strap.

Subsystem Requirements

Subsystem 1: Power Subsystem

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).

Requirement	Validation Process
The subsystem must output 3.3V ±0.2V (for the microcontroller and MPU6050) and 5.0V ±0.2V (for the display and motor).	The battery will be connected to the buck converter and voltage regulator, and we will use a multimeter to measure a 5V output from the buck converter and 3.3V output from the linear regulator
The battery must support ≥2 hours of continuous operation under peak load (300mA @ 5V, 100mA @ 3.3V).	A fully charged battery will be connected and while continuously monitoring the voltage output on both rails, we will keep a timer of how long it will take for the battery voltage to drop past minimum the voltage requirements (3.1V for 3.3V rail and 4.8V for 5V rail)

Includes overcurrent protection on both output rails. Interfaces: Input: 12V LiPo battery. Outputs: 5V (to microcontroller, MPU6050) and 5V (to display, motor).	Test overcurrent protection on both 5V rails (12V LiPo input) using an electronic load. Verify each rail (microcontroller: ≤500mA, motor: ≤1A) triggers protection (voltage ≤1V) within 100ms when overloaded. Confirm normal 5.0V±0.2V resumes post-fault. Tools: multimeter, load.

Subsystem 2: Feedback Subsystem

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.

Requirement	Verification
The 8-segment display must update within 1s of a detected rep.	We will use a motion that will mimic a repetition and start a timer at the moment the system detects a repetition and stop it once the led increments
The vibration motor must vibrate strong enough such that it is felt by the user	Each team member will test various vibration intensities and will rank them based on the criteria of how well the vibration is felt, and how little it impairs their movement. These rankings will be used as a consensus to
The display must support 1-digit output (0–F)	We will perform the movement of a repetition 15 times, carefully making sure each digit is properly displayed

Subsystem 3: Sensing Subsystem

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.

Requirement	Verification
The MPU6050 must sample acceleration/gyro data at ≥ 50Hz.	Connect the MPU6050 to the microcontroller and upload firmware that streams raw sensor data via a serial port. Program the microcontroller to toggle a GPIO pin each time a sensor sample is read. Measure the pin's frequency using the oscilloscope.
The potentiometer must adjust TUT in 1–10s increments using a dial.	Rotate the potentiometer dial incrementally from its minimum to maximum position. For each dial position, record the TUT value displayed on the serial monitor (e.g., "TUT Set: 3s"). Verify that the TUT value increments/decrements in 1s steps (1s, 2s, ..., 10s) as the dial is adjusted.
Automatic calibration on startup to zero the sensor when idle for ≥5s.	Place the device on a stable surface to ensure no motion. Power on the device and wait 5 seconds to check if the calibration is set to zero. Pre-calibration data must show

	near-zero values (±0.05g for accelerometer, ±0.5°/s for gyro) after the 5s idle period. Post-calibration motion data must reflect actual movement (e.g., >0.5g change during lifting).

Subsystem 4: Microcontroller Subsystem

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.

Requirement	Verification
Native I2C ports must interface with MPU6050	Oscilloscope checks SCL/SDA lines during data transmission for stable clock and ACK signals.

The PWM pin must output 500 Hz ±50Hz (motor control).	Oscilloscope measures PWM frequency/duty cycle during motor activation.

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.

Cost and Schedule

Cost Analysis

Formula: ($/hour) x 2.5 x hours to complete = TOTAL

Assuming the average graduate from ECE at Illinois makes about $50 per hour,

$50/hr * 2.5 * 10 hrs/week * 12 weeks = $15,000 per group member

For 3 group members => 3 * 15,000 = $45,000

Description	Manufacturer	Quantity	Cost (each)	Link
ATmega328P	Microchip Technology	4	$2.89	Link
MPM3550EGLE	Mouser Electronics	1	$13.11	Link
LM1117MP-3.3	Mouser Electronics	1	$1.38	Link
MPU6050	Hiletgo	3 pack	$10.99	Link
7 Segment Display	ProtoSupplies	3	$4.95	Link
Flat Coin Vibration Motor	Diann	1	$5.99	Link
2N3904 Diode	Digikey	10	$0.46	Link

Schedule.

March 10th - March 17th	● Build and demo the breadboard prototype. ● Finish ordering all the parts that were not used for the breadboard demo. ● Make sure the breadboard prototype works with the buck converter and linear regulator.
March 18th - March 24th	● Design the CAD model for the machine shop. ● Solder the PCB to check for working/not working components. ● Make edits to the PCB as needed for the order.
March 25th - March 31st	● Program ATTmega328 with the MPU attached to the PCB. ● Make the display work with a microcontroller. ● Work on condensing the PCB design so it could fit in a smaller case.
April 1st - April 7th	● Install the product into the case. ● Test for the sensor requirements being fulfilled. ● Test for the power requirements being fulfilled.
April 8th - April 14th	● Work on the final demo presentation.

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.

Citations

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1. MPM3550E. 36V, 5A, High-Efficiency, Fast Transient, Non-Isolated, DC/DC Power Module with Integrated Inductor | MPS. (n.d.). https://www.monolithicpower.com/en/mpm3550e.html

2. MPU6050 (gyroscope + accelerometer + temperature) interface with .. MPU6050 (Gyroscope + Accelerometer + Temperature) interface with .. (n.d.-a). https://www.electronicwings.com/avr-atmega/mpu6050-gyroscope-accelerometer-temperature-interface-with-atmega16

3.ATMEGA328P.(n.d.-a).https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-7810-Automotive-Microcontrollers-ATmega328P_Datasheet.pdf

4. hk_jh. (2023, July 9). Controlling mini vibration motors with MOSFET instead of BJT.Arduino Forum.https://forum.arduino.cc/t/controling-mini-vibration-motors-with-mosfet-instead-of-bjt/1146260

5. IEEE - IEEE Code of Ethics.(n.d.).https://www.ieee.org/about/corporate/governance/p7-8.html