RunCompanion

Team 10

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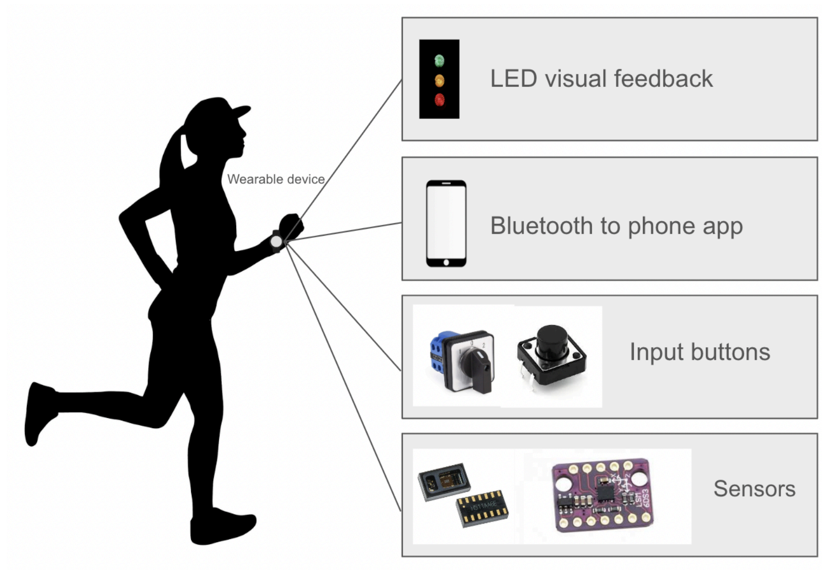
1. Introduction

a. Problem: Many runners struggle to optimize their training because most workout devices on the market only provide static data — like steps, heart rate, and distance—without offering dynamic, real-time feedback based on the actual conditions of their run. Existing fitness devices often fail to guide users during their workout, meaning runners don't receive personalized advice on adjusting their pace or effort in response to changes in their physical state. This lack of adaptive guidance can prevent runners from reaching their full potential, increasing the risk of injury and making it harder to achieve fitness goals. A solution that dynamically integrates multiple sensor inputs to provide real-time, actionable feedback would help runners make informed decisions and optimize their performance during their workout.

b. Solution: Our product is a wearable device designed specifically for runners that provides dynamic, real-time feedback throughout their workout. The device includes buttons for easy input, allowing users to select their run type—whether it's an easy jog, normal run, pace booster, HIIT training, or recovery run. Once the workout begins, the device activates multiple sensors to monitor various aspects of the run. The heart rate sensor provides immediate feedback on whether to speed up or slow down based on the selected workout mode. We will combine the IMU data with heart rate data and algorithmically generate feedback displayed via an LED. Post-workout, the device offers comprehensive feedback through data visualization, stored on a phone app. . All sensor data is processed by the ESP32 microcontroller, which uses its built-in Bluetooth capability to transmit information to a mobile app, where the user can analyze their performance in detail.

c. Visual Aid:



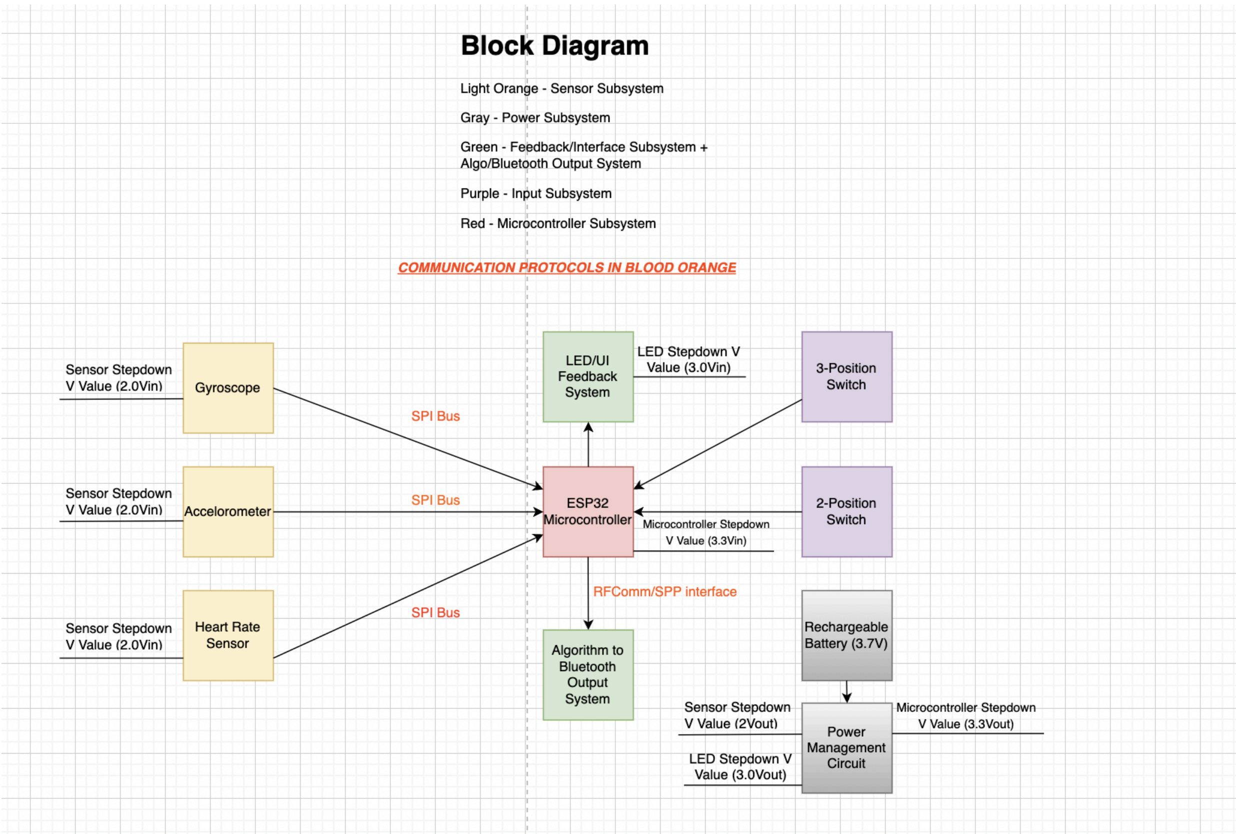
d. High Level Requirements List:

i. We expect heart rate data to be at an accuracy of ±5 BPM. The heart rate sensors should also sample data at 1Hz.

ii. Our IMU unit will include both the accelerometer and gyroscope. For the gyroscope, we're expecting an average variation of ±1°/sec, while for the accelerometers we are expecting an accuracy rating of ±0.01g. We want a sample rate for both components of the IMU to be as close to 100 Hz as possible. (80-100 Hz range is OK).

iii. The product shall be powered by a rechargeable Lithium-Ion battery, running at normal-performance (3.7V, 400-500mAh) and charge via USB-C. We expect the battery to function at full-performance for approximately 1.5 hours.

2. Block Diagram:



Subsystems:

1. Sensor Subsystem

- **Heart Rate Sensor (MAX30102EFD [1])**:
  - **Voltage**: 1.8V – 2V
  - **Current Draw**: 0.6 – 1.1 mA (peak)
  - **Description**: Continuously monitors the user's heart rate, providing real-time feedback on whether the user should speed up, slow down, or maintain their current pace. The heart rate sensor is critical for managing workout intensity and performance.
  - **Requirements**:
    - The sensor must accurately transmit real-time heart rate data to the microcontroller.
    - It must operate with minimal latency, with a maximum delay of 1 second for data transmission to ensure timely feedback.
- **Accelerometer & Gyroscope (STM LSM6DS3 [2])**:
  - **Voltage**: 1.8V – 3.6V
  - **Current Draw**: 0.9 - 1.25 mA
  - **Description**: Tracks the user's movement and form. The accelerometer monitors linear motion, while the gyroscope tracks rotational movement, allowing for comprehensive form analysis and pace adjustment recommendations.
  - **Requirements**:
    - The accelerometer and gyroscope must transmit accurate rotational and linear data to the microcontroller.
    - Low power consumption and a response time of less than 50ms are essential for real-time feedback adjustments.
- **Connection to Other Units**:
  - The sensors connect to the microcontroller for data processing and to the power subsystem for power supply.

2. Input Subsystem (User Interface)

- **Rocker 3 Position Switch (R4DBLKBLKBF0 [3])**:
  - **Voltage**: none needed
  - **Current Draw**: no current drawn
  - **Description**: Allows users to select their workout mode (e.g., Easy Jog, HIIT, Recovery Run). Each position corresponds to a distinct workout mode.
  - **Requirements**:
    - The switch must reliably transmit signals to the microcontroller with a response time under 1 second.

        - It should provide clear feedback when switching between modes.
- **Rocker 2 Position Switch (RA1113112R-3457780 [4])**:
    - **Voltage**: none needed
    - **Current Draw**: no current drawn
    - **Description**: There will be two modes for either starting or stopping the workout. Once we are in the start state, the sensors will start recording data.
    - **Requirements**:
        - The switch must send signals to the microcontroller within 1 second.
        - The switch should be clearly labeled and intuitive to use during the workout.
- **Connection to Other Units**:
    - The switches connect to the microcontroller for processing the workout mode and for controlling the start/stop functionality.

3. Microcontroller Subsystem

- **ESP32 Microcontroller [5]**:
    - **Voltage**: 3.0V – 3.6V (typically runs at 3.3V)
    - **Current Draw**: 120 mA (active) + 160 mA (Bluetooth enabled)
    - **Description**: The central processing unit of the system, responsible for managing sensor data, real-time processing, and transmitting data via Bluetooth to a mobile app for post-workout analysis. It also controls the LED feedback system to provide immediate workout guidance.
    - **Requirements**:
        - The microcontroller must handle real-time data from sensors with less than 50ms delay.
        - Efficient Bluetooth transmission to the mobile app, with data sync within 1 second.
        - The microcontroller must drive the LED feedback system based on sensor data.
- **Connection to Other Units**:
    - The microcontroller connects to the IMU (via SPI) and heart rate sensor (via SPI) for data processing.
    - It also connects to the buttons and the 3-position switch for mode selection and workout control.
    - Additionally, the microcontroller communicates with the feedback system (LEDs and phone app) and connects to the power subsystem for power management.

4. Feedback Subsystem (Software)

- **LED Feedback System (150080BS75000 [6])**:

- **Voltage**: 2V – 3V (per LED)
- **Current Draw**: 10 – 20 mA (per LED)
- **Description**: Provides real-time visual feedback via color-changing LEDs. The system uses a traffic light-based indicator to guide the user:
    - **Green**: Speed up.
    - **Yellow**: Slow down.
    - **Red**: Stop or take a break.
- **Requirements**:
    - LEDs must provide clear real-time feedback, with color changes within 1 second of receiving a signal from the microcontroller.
    - The system must be energy-efficient and avoid excessive battery drain.

- **External Phone Application**:
    - **Description**: The mobile app provides post-workout statistics based on data from the accelerometer, gyroscope, and heart rate sensor. It will display data visualizations to help users improve their performance.
    - **Requirements**:
        - The app must provide meaningful feedback based on the entire workout session, with data visualizations.
        - The data must be transmitted to the mobile application's database within 1 minute of completing the run.
- **Connection to Other Units**:
    - The LEDs and phone app connect to the microcontroller for receiving sensor data and feedback. The LEDs also connect to the power subsystem for power supply.

5. Power Subsystem

- **Rechargeable Battery**:
    - **Voltage**: 3.7V (Li-Po)
    - **Capacity**: 500 mAh
    - **Description**: Powers all subsystems, including sensors, microcontroller, and LEDs. The battery is rechargeable via USB-C and includes a power management circuit to optimize energy usage.
    - **Requirements**:
        - The battery must power the device for at least 1.5 hours of continuous operation.
        - Power must be distributed efficiently across all subsystems to prevent excessive current draw.
- **Power Management Circuit**:
    - **Voltage**: 3.7V ± 0.1V
    - **Current**: Must supply at least 342 mA continuously

   - **Description**: Ensures efficient power distribution, optimizing battery life and preventing power surges that could damage components.
   - **Requirements**:
      - Must provide at least 342 mA continuously at 3.7V.
      - Must include overcurrent protection to prevent excessive current draw.
- **Connection to Other Units**:
   - The power subsystem connects to all other subsystems to supply necessary power for operation.

Tolerance Analysis

The total current draw of the system is a critical factor in ensuring that the design will function as expected, without overloading the power supply or causing system instability. Here are the calculations to ensure that the power requirements are within the limits of the battery capacity.

- **Total Current Draw**:
   - **ESP32 Microcontroller**: 280mA (active + Bluetooth)
   - **Heart Rate Sensor**: 1.1mA
   - **Accelerometer & Gyroscope**: 1.25mA
   - **3-Position Switch**: 0mA
   - **2-Position Switch**: 0mA
   - **LED Feedback System (3 LEDs)**: 60mA

   Total Current = 280mA + 1.1mA + 1.25mA + 0mA + 0mA + 60mA = 342.35mA

- **Battery Life Calculation**:
  The system uses a **500mAh** battery, so the battery life can be calculated as follows:
  Battery Life (hours) = 500mAh / 342.35mA ≈ 1.46 hours
- This is sufficient for a typical workout session, as the system will last approximately **1.46 hours** under full load.
- **Voltage Consistency**:
  The **3.7V Li-Po battery** is compatible with all components, and voltage regulation will ensure stable power supply. Components that operate below 3.7V (e.g., the heart rate sensor at 1.8V) will receive regulated power to prevent over-voltage issues.
- **Overcurrent Protection**:
  The power management system will include overcurrent protection to prevent any component from drawing excessive current, protecting the system from potential damage or instability.

- **Noise Reduction (FIR Filtering)**:
  FIR filtering will be applied to sensor data (especially the accelerometer and gyroscope) to reduce noise and improve accuracy, ensuring reliable real-time feedback.

With a total current draw of **342.35mA** and a **500mAh battery**, the system will function effectively for **1.46 hours**. The voltage and current requirements of each component are well within the operating capacity of the battery and power management system, ensuring reliable performance throughout the workout session.

Ethics & Safety

Taking a look at the “IEEE Code of Ethics” [7] and the “ACM Code of Ethics and Professional Conduct” [8], there are some guidelines this project must follow to adhere to them to be beneficial towards society. This project is in guidelines with with specifically I.1 within the IEEE Code of Ethics as it states, “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment” [7] and this project successfully satisfies those conditions [7]. Furthermore, this project also satisfies the ACM Code of Ethics where it states, “Contribute to society and to human well-being, acknowledging that all people are stakeholders in computing.” in section 1.1 [8].

This wearable device made for runners is focused on only monitoring and improving their running performance through real-time feedback based on heart rate and respective movement data. It is made to enhance the user’s running experience and to optimize their workouts, hence it is a positive tool. The data collected is utilized to improve the runner’s experience/workout by guiding improvements on their pace, form, and effort. Beyond the information regarding running performance, the system does not collect any unique identifier information. This reduces the risk of this product for being used unethically.

In addition, by helping runners with optimizing their workouts, the device will be able to help with reducing the risk of injury, which is commonly seen in poorly planned/followed workout routines. The ethical positivity of this project is the fact that it is promoting health and fitness, to aid in the end user to achieve their workout goals safely. The ACM Code of Ethics encourages the development of technologies that benefit human well-being [8]. As this product is directly aimed towards benefitting humans this project satisfies that requirement. The device also utilizes data-based scientific feedback to users, hence it does not mislead the user. This also supports the positive morality about the project. Due to all of these reasons, this project aligns with ethical standards and has a clear societal benefit.

There are some safety issues to consider when sensors such as the MAX30102EFD [1] heart rate sensor and the STM LSM6DS3 [2] accelerometer and gyroscope are being used. The accuracy of the heart rate sensor must be accurate as any improper readings can alter the output of the real-time dynamic feedback provided by the algorithm hence causing improper and even dangerous workout intensities. To mitigate this issue, we will use redundant signal filtering using FIR filtering to minimize noise without introducing any phase delays. This will ensure that the feedback will be reliable and correct. To further test the various scenarios, we will test in various environments to calibrate and test sensor accuracy in a wide variety of real-world scenarios.

The safety of the 3.7V 500mAh Li-Po rechargeable battery is also a concern of this developed device. Possible issues could be overheating, short circuiting, and even fire, and to mitigate all of these scenarios, the battery will be housed in an enclosure to protect it from sweat, dust, impact, and even possible punctures. This enclosure to satisfy all of these conditions will be made out of a non-conductive hard material such as plastic. This battery enclosure will also have to be water resistant to prevent any moisture from infiltrating the battery enclosure causing issues.

Additionally, the wiring of this device must be secured and insulating to prevent any short circuits and interference with the sensor readings. The wires connecting the heart rate sensor, accelerometer, and gyroscope will be secured to prevent them from becoming loose or frayed due to the vibration during running. If they were to come loose, the accuracy of the sensors will drop very drastically. Overall, by ensuring that the battery and the wired connections are durable and secured, the accuracy of the overall system can be assured. As stated earlier, it was stated that this project will satisfy both the IEEE Code of Ethics and the ACM Code of Ethics, and through the later detailed paragraphs it has been shown that it is in fact true. This project will be transparent so the end users will always be informed about their rights and safety in regards to the use of this product.

References

[1] MAX30102EFD+T Analog Devices inc./maxim integrated | ... (n.d.-c). https://www.digikey.com/en/products/detail/analog-devices-inc-maxim-integrated/MAX30102EFD-T/6188734

[2] *LSM6DS3TR-C*. STMicroelectronics. (n.d.). https://www.st.com/en/mems-and-sensors/lsm6ds3tr-c.html

[3] R4DBLKBLKBF0 E-switch - digikey. (n.d.-d). https://www.digikey.com/en/products/detail/e-switch/R4DBLKBLKBF0/1805285

[4] RA1113112R e-switch | switches | DigiKey. (n.d.-d). https://www.digikey.com/en/products/detail/e-switch/RA1113112R/3778055

[5] *Arduino® Nano ESP32*. Arduino Online Shop. (n.d.). https://store-usa.arduino.cc/products/nano-esp32

[6] 150080BS75000 Würth Elektronik | optoelectronics | DigiKey. (n.d.-a). https://www.digikey.com/en/products/detail/w%C3%BCrth-elektronik/150080BS75000/4489912

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

[8] *The code affirms an obligation of computing professionals to use their skills for the benefit of society.* Code of Ethics. (n.d.). https://www.acm.org/code-of-ethics