ECE 445
Senior Design Laboratory
Project Proposal
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Ambient Lighting System

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1 Introduction

1.1 Problem

In many environments, the ambiance is heavily influenced by lighting, which often requires manual adjustment to match the mood of the space. This can be inconvenient and limits personalization. What if we had a system that could track how you are feeling and adjust the lighting system accordingly? We propose an individual lighting experience that acts as a dynamic lighting system, reacting to sound and heart rate to provide a personalized, immersive environment. This system would eliminate the need for manual intervention, offering a more cohesive ambiance that changes based on both noise and the user's emotional state.

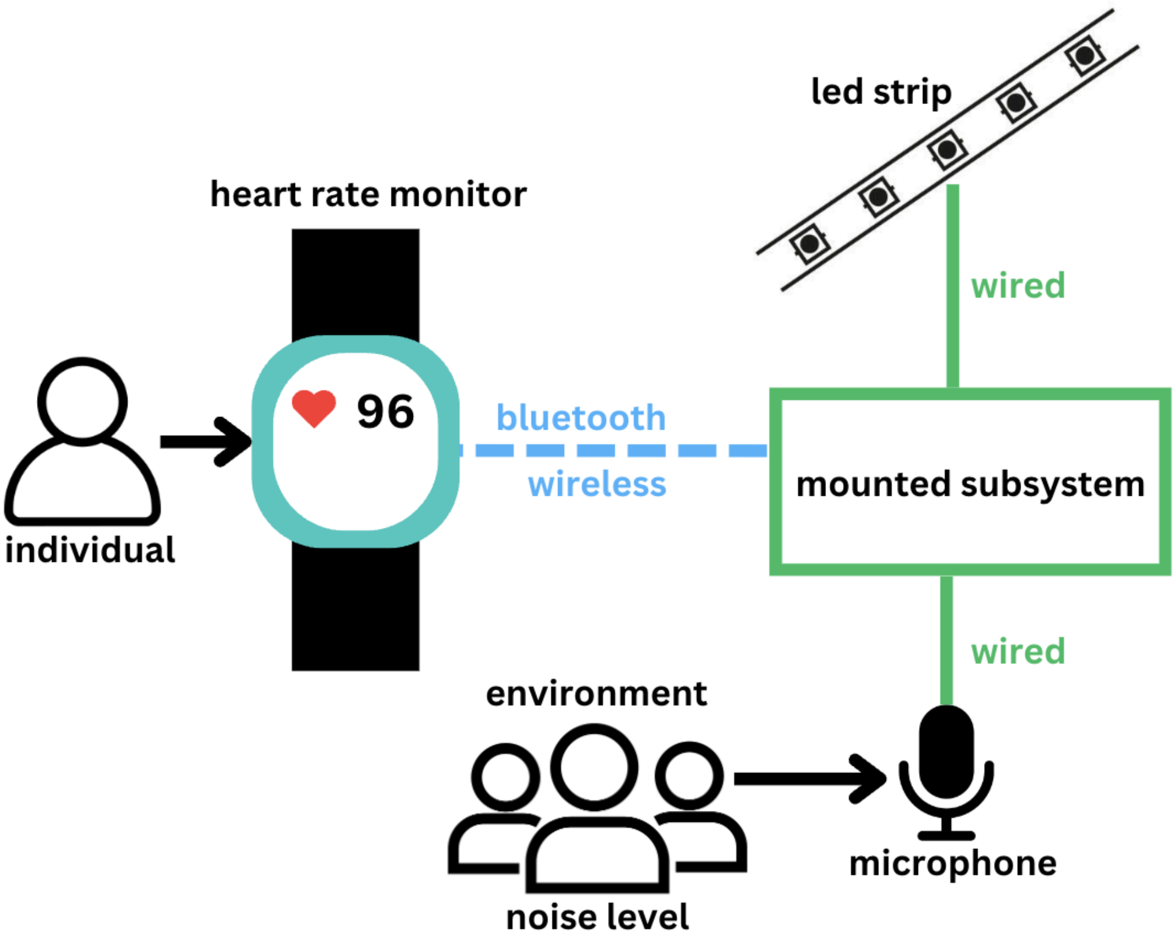
For example, if a user is watching an action movie or playing music, the system will synchronize lighting with the intensity of the scene or sound. In addition, the system adjusts the brightness based on the user's heart rate, creating a unique experience tailored to their mood and activity.

1.2 Solution

Our project proposes the development of an intelligent lighting system that connects LED strips, which can be placed behind a TV, painting, or near a speaker. The system automatically synchronizes with the background noise of the user's activity, while also adjusting intensity based on the user's heart rate. This enhances the user experience by providing adaptive lighting that is highly personal and responsive.

At a high level, we have an audio system that collects background audio and sends signals to change the color of the LED strip. Additionally, a heart monitor system connects to the circuit via Bluetooth and sends signals to adjust the intensity of the LED strip—brighter for higher heart rates and dimmer for lower heart rates.

1.3 Visual Aid

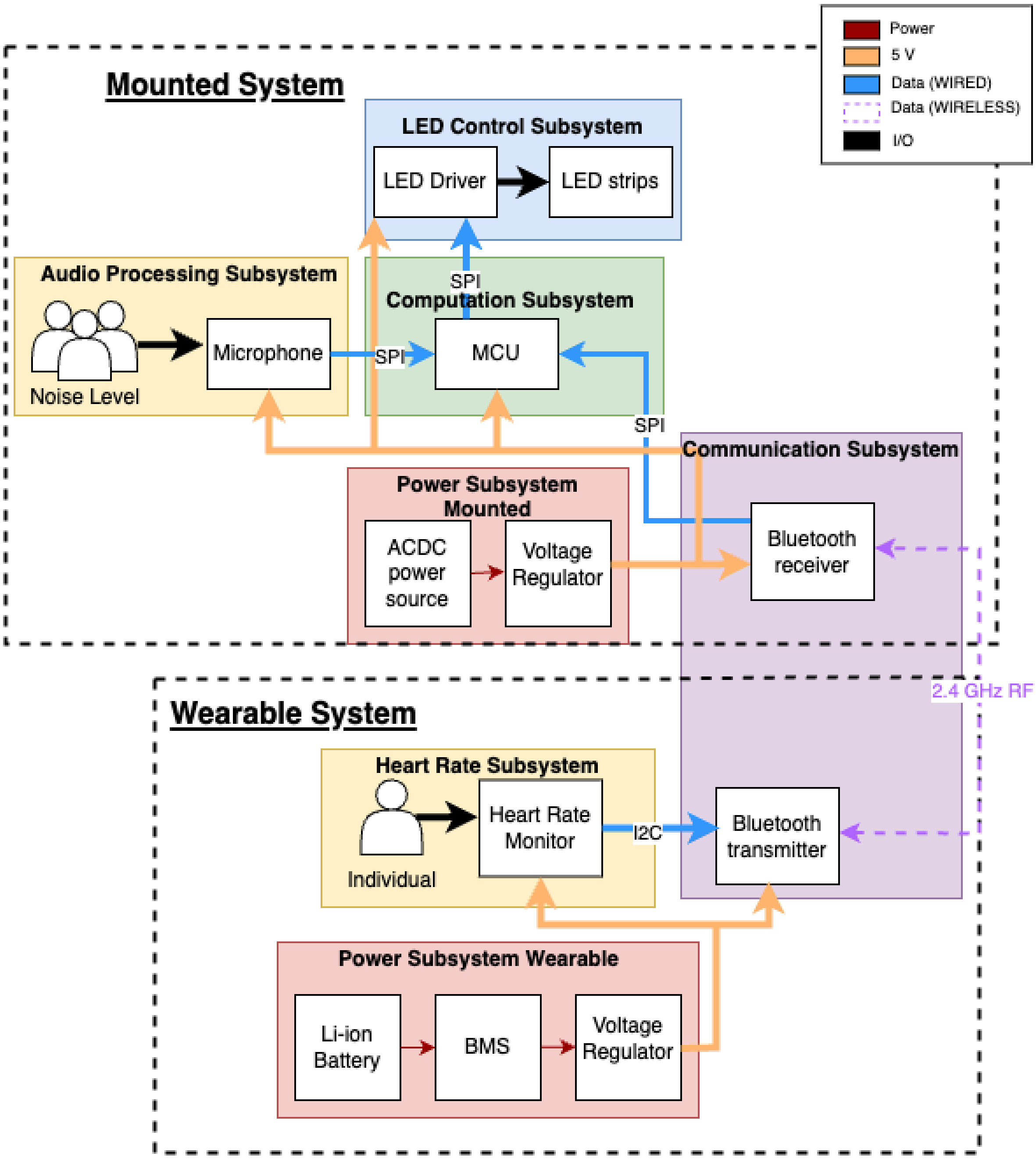


1.4 High-Level Requirements

- The system must detect and respond to changes in noise levels, adjusting the LED color within 50ms.
- The heart rate monitor must accurately transmit data, allowing for brightness adjustments within 100ms of detecting a change in heart rate.
- The LED strip must support a full range of 10 colors and brightness levels from 200 lumens to 450 lumens, allowing for highly customizable lighting experiences based on sound and heart rate.

2 Design

2.1 Block Diagram



2.2 Subsystem Overview

2.2.1 Audio Processing

This subsystem captures and processes audio input to detect noise levels and changes in frequency. Using a MEMS microphone, it converts sound waves into electrical signals. These signals are processed by the MCU using algorithms like Fast Fourier Transform (FFT) or amplitude-based analysis to interpret noise levels and frequency variations. This data is crucial for adjusting the LED colors, allowing the system to respond to the surrounding audio environment dynamically.

This subsystem interfaces directly with the MCU, providing audio data that influences the LED Control System for color adjustments. The power subsystem directly supplies power to the microphone. The audio processing system isn't influenced by the communication subsystem, the wearable subsystem, or the heart rate subsystem and it has no direct interaction with it.

2.2.2 Heart Rate Monitor

This subsystem collects heart rate data using the pulse oximeter and sends it to the MCU via a Bluetooth module. The MCU then uses this information to regulate the intensity of the LED strip, adjusting brightness in real-time. The heart rate data ensures that the system can react to physiological changes, creating an interactive lighting effect based on the user's heart rate.

This subsystem transmits heart rate data to the MCU, which combines it with audio data to adjust the brightness of the LED lights. It will also receive power to the heart rate monitor from the power subsystem.

2.2.3 LED Control System

It manages the color and brightness of the LED strips. The LED driver receives control signals from the MCU, which processes both the audio input and heart rate data. Pulse Width Modulation (PWM) is used to control the brightness, based on heart rate, while color changes are driven by the audio analysis. This allows for fine-tuned, real-time control over the LED display, making it responsive to both environmental sounds and physiological signals.

This subsystem is controlled by the MCU, which uses data from both the Audio Processing and Heart Rate Monitor subsystems to adjust the LED lights. The LED driver will also receive power from the voltage regulator in the power subsystem.

2.2.4 Power Management System (Mounted)

This system converts the incoming 120V AC power supply into a stable 5V DC output, which is used by the mounted subsystems, including the MCU, LED control system, and audio processing system. It ensures that all components receive the appropriate voltage and current to function correctly without overloading or damaging the system. This subsystem is crucial for the continuous operation of the system, as power instability would disrupt the functionality of the entire setup.

The mounted power management system powers the MCU, the LED Control System, the Audio Processing subsystem, and the bluetooth receiver, which is part of the communication subsystem with a constant 5 V output and up to 100mA of current. It does not interact with the wearable power management subsystem, the heart rate monitor, or the transmitter part of the communication subsystem.

2.2.5 Power Management System (Wearable)

The wearable power management system powers the heart rate monitoring subsystem, ensuring that the heart rate sensor and Bluetooth transmitter have enough power to function correctly. It manages the battery to prevent it from drawing more than 500mA of current, extending battery life and enabling uninterrupted use. If the wearable power management fails, the heart rate monitor would lose power, leading to a loss of synchronization between the heart rate and the lighting system.

The wearable power management system directly powers the heart rate system and the transmitter part of the communication subsystem. It does not interact directly with any other subsystem.

2.2.6 Communication Subsystem

This subsystem allows for communication between the wearable heart rate monitor and the mounted system, which has the MCU and does all the computation. This subsystem consists of a bluetooth transmitter and a bluetooth receiver.

The communication subsystem takes the data from the heart rate monitor and communicates that with the MCU in the mounted subsystem. It gets power from the wearable power subsystem. This subsystem does not directly interact with the mounted power subsystem, the LED driver, or the audio processing subsystem.

2.2.7 Computation Subsystem

This subsystem takes the audio information from the audio processing subsystem and the heart rate information from the wearable subsystem and does the necessary calculations to convert that into RGB values that that LED driver will read so the LED strip changes to the appropriate color at the appropriate time.

This subsystem consists of an MCU. It is powered by the mounted power subsystem, takes in input from the audio processing subsystem, the communication subsystem and outputs that data to the LED control system. It doesn't interact with the wearable power subsystem or the heart rate monitor.

2.3 Subsystem Requirements

2.3.1 Heart Rate Monitoring Subsystem

- The heart rate sensor must provide accurate data within ±10 BPM.
    - If heart rate data was not accurate, the reaction of the lights would not be proportional to the reaction that the user is experiencing.
- Heart rate data should be transmitted to the MCU via Bluetooth within 150 ms of measurement.
    - Brightness should adjust proportionally to heart rate changes.
    - Something to note is that the MCU is also connected to the rest of the mounted system(shown in the block diagram above)
    - If the data isn't transmitted within that time frame, the reaction will be delayed and the lights will not align with the movie or the heart rate.
- Brightness should adjust proportionally to heart rate changes. For every 10 BPM change, there should be a 10% change in brightness.
    - The entire point is for there to be a reaction to the heart rate, so if there is no change, the heart rate does not contribute to the user experience.
- List of Requirements:
    1. Power has to be supplied to the heart monitor or else the heart monitor would stop working.
    2. The bluetooth transmitter also has to work for seamless wireless data transfer to the bluetooth receiver in the mounted subsystem, or else we cannot analyze the data to provide a proper output.
    3. Heart rate monitor must work and not be faulty to ensure that correct data is transferred

2.3.2 LED Control Subsystem

- The LED control system adjusts both the color and brightness of the LED strip depending on the output from the MCU
- The components are LED drivers and the actual LED strip
- List of Requirements
    1. Must be able to change the LEDS over 20 different colors. If the colors don't change, the LEDs don't have any effect on the user or the user's experience.
    2. The LEDs must be able to pulse a maximum 120 beats per minute. If the LEDs don't pulse, then the user won't be able to experience the sync of whatever they are watching to the LEDs

2.3.3 Audio Processing Subsystem

- This subsystem is responsible for capturing the audio input to the LED control system. The MEMS microphone converts the sound waves into electrical signals that can be analyzed. The amplitude-based analysis is used to determine the beat and noise level of the music which will be sent to the LED system and change the colors and brightness.
- This subsystem is important because always the LED changes based on surrounding sound and without it there would be no detection of sound level which leads to failure to change the color which is a high-level requirement.
- Interfaces with Other Subsystems:
    - Microphone to MCU
        - The microphone will receive the analog sound input and convert it to be sent to the MCU. The MCU must receive signals within a voltage range 0-3.3V.
    - Audio Data to LED
        - The data must be updated every 150 ms to ensure synchronization of the LED's behavior to the audio input being sent.
- List of Requirements
    1. Power must be supplied to the microphone of 1.8-3.3V.
    2. The microphone must be able to capture audio data within 20 dB of the actual sound to ensure an accurate representation of the environment or video. Without this, the LED response will not be accurate and reflect the real audio.

2.3.4 Power Management Subsystem(Mounted)

- This subsystem is required to power the LED Driver, the MCU, and the Audio processing unit. It provides a steady output of 5V to power all of these subsystems to ensure proper functionality. The subsystem consists of an AC/DC converter, since this will be plugged into a wall outlet, and a voltage regulator to output the 5V.
- List of Requirements

1. Must be able to accurately convert the AC 120V input to a more usable 5V output for various other mounted subsystems. If there is no power, or it is too high of a voltage, then the system won't be able to operate or the parts will burn out.

2.3.5 Power Management Subsystem(Wearable)

- This subsystem will power the bluetooth transmitter and the heart rate monitor. It consists of a 5V battery, a battery management system, and a voltage regulator. It will output a consistent 5V to all of the other subsystems.
- If this subsystem fails, then the bluetooth and heart rate monitor won't operate as expected.
- List of Requirements
    1. Must not draw more than 500mA of current to preserve battery life.
    2. If the battery dies, then the fundamental part of the entire system (heart rate monitor) doesn't contribute to the user experience.

2.3.6 Communication Subsystem

- This subsystem is used for the bluetooth transmitter and receiver. It connects the wearable system to the mounted system via wireless connection. It requires 5V to be powered
- If this subsystem fails, then the heart rate monitor's data will not properly be sent to the mounted system
- List of Requirements
    1. Must work within a range of 10 meters
    2. The Bluetooth transmitter should successfully pair with the receiver
    3. Must reliably transmit heart rate data from the wearable system to the mounted system without inconsistencies

2.3.7 Computation Subsystem

- This subsystem is used to calculate all the data given by the Audio Processing subsystem along with the Communication Subsystem which will then have an output for the LED driver that signals the luminescence and color of the led
- If this subsystem fails, then the LED lights will not accurately display the proper output
- List of Requirements
    1. Must receive and process audio information from the audio processing subsystem
    2. Must accurately process the audio and heart rate data to convert it into the correct RGB values and luminescence that the LED driver can interpret for color changes

2.4 Tolerance Analysis

1. **Data Size and Transmission Feasibility:**

- Data Size for Heart Rate: Assuming the heart rate value is an integer, it requires 4 bytes (32 bits) for transmission.
- Bluetooth Bandwidth: At 1 Mbps, the Bluetooth module transmits 1 Megabit per second or 1,000,000 bits per second.
- **Transmission Time Calculation:**
  - Time to Transmit 32 bits: The time to transmit the 32-bit integer is: Transmission Time=1,000,000 bits/sec32 bits=32×10−6 sec=32 microseconds.
  - This time is negligible compared to the requirement of 50 ms for transmission, so the transmission rate is well within the allowable tolerance.

2. **Transmission Latency and Buffering:**
   - Bluetooth Latency: Standard Bluetooth Low Energy (BLE) has a typical latency of 10 ms to 20 ms depending on environmental factors like interference. To account for worst-case scenarios, we assume the maximum latency of 20 ms.
   - Total Latency: The total communication delay will be the sum of the Bluetooth transmission time and any additional system processing or buffering. Since the transmission time is negligible (32 microseconds), the total latency is effectively dominated by the Bluetooth latency, which is 20 ms.
   - This leaves a 30 ms buffer for processing at the MCU, well within the requirement of 50 ms.
3. **Power Supply Tolerance:**
   - The Bluetooth transmitter operates at 5V, with a tolerance of ±0.1V. Power fluctuations could cause performance degradation or interruptions.
   - Power Tolerance: The voltage regulation circuitry needs to ensure that the Bluetooth module is supplied with a stable 5V ± 0.1V. This is achievable with standard voltage regulators that maintain accuracy within 1-2% of the nominal voltage. Hence, the power supply tolerance will not pose a significant challenge.
4. **Mathematical Analysis of Time Constraint:**
   - Let's define the variables:
     - t_s= sampling interval = 100 ms,
     - t_{bt} = Bluetooth transmission time (including latency) = 20 ms,
     - t_{proc}= MCU processing time = 10 ms (worst case).
     - Total time, t_{total}, for data sampling, transmission, and processing: $t_{total}=t_s+t_{proc}+t_{proc}$=100 ms+20 ms+10 ms=130 ms
   - Since the system must complete the heart rate monitoring cycle within 150 ms, we have.

     t_{total}=130 ms<150 ms.

   - Therefore, the timing requirements are feasibly met, with a 20 ms buffer.

By analyzing the heart rate data transmission subsystem, we can see that the **Bluetooth transmission time**, **latency**, and **processing time** all fit well within the given **150 ms constraint**. The power supply requirements also fall within standard tolerances. Hence, with the given design parameters, the subsystem can **feasibly meet** its performance requirements, and the risk of failure due to timing or power issues is minimal.

3 Ethics and Safety

Since we are using heart rate data and background noise, there is an issue if someone were to access that data and use it for malicious endeavors. According to ACM Code of Ethics(1.6), we have to respect their privacy and take steps to ensure that their personal data is protected such as not storing their data. As per IEEE Code of Ethics (Section 1), developers should disclose risks and obtain consent before using systems that use user data. Users should be made aware of how their data will be used and processed. It should be accessible to individuals with disabilities, as per the ACM Code of Ethics (1.4), which mandates fairness and non-discrimination. However, we will have a warning before using this system since the lights flashing and changing intensity could hurt some people's eyes. Excessive brightness, flickering, or rapid changes in light could cause eye strain or migraines. We will ensure that the lights do not flicker too rapidly and change brightness fast enough to cause eye strain. The heart rate monitor must follow safety guidelines such as IEC 60601-1. The wearable device should not overheat for the safety of the user. Ensuring that the wearable does not overheat or malfunction is critical to user safety. Overall, we will make sure not to store and distribute the heart rate data. The system will also be easy to turn off if the lights become too much for any user.