ECE 445

Project Proposal

BioSteady

Team 46

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1. INTRODUCTION

1.1 Problem

Coffee and caffeinated beverages have become amongst the most sought after stimulants consumed by individuals who experience high stress levels due to the fast-paced and demanding nature of their academic and professional lives. We are constantly in an environment where the presence of cafes and vending machines are all around which makes it difficult for individuals to resist when they are looking for a way to maintain productivity for long periods of time. In such scenarios, we fail to acknowledge the negative physiological changes that affect our overall health in the long term.

Both stress and caffeine independently trigger these responses which particularly include increase in heart rate and changes in skin conductance. It is challenging to differentiate between the overlapping effects, which leads to overconsumption of caffeinated beverages with detrimental effects on one's health. Research suggests that the intake of caffeine, especially under mentally stressful conditions can increase the risk of developing anxiety or depression in young adults. This makes it essential for us to find a reliable way to differentiate between the physiological changes triggered by caffeine and stress in real-time so that we are able to make informed health-related decisions in the long term.

1.2 Solution

Our proposed solution is to ideate and build a wearable device that collects physiological data through the sensors used to estimate and report to users whether their bodily changes are likely influenced by caffeine intake or stress. This information will help users decide whether consuming caffeine at a given moment is advisable. Stress causes a "fight or flight" response which is induced by adrenaline, leading to rapid spikes in heart rate and sudden fluctuations in skin conductance. On the other hand, caffeine causes a slow and gradual increase in heart rate over 10-20 minutes with an eventual rise in skin conductance.

This report will be displayed through a custom built web application which will also provide recommendations to users regarding caffeine consumption and stress management techniques. A considerable amount of research led us to a study which graphically demonstrates a significant difference in sensor readings with respect to stress and caffeine. Leveraging these trends and machine learning algorithms, we can effectively classify levels of stress and caffeine intake in one's body (Villarejo et al., 2012).

The table below summarizes our expected sensor readings:

	HEART RATE (HR)	SKIN CONDUCTANCE (GSR)
STRESS	Sudden spike in heart rate because of adrenaline release	Sudden and irregular fluctuations in skin conductance
CAFFEINE	Gradual and steady increase over 10-15 minutes	Initially stable or low for about 200 seconds followed by a steep increase

1.3 Visual Aid

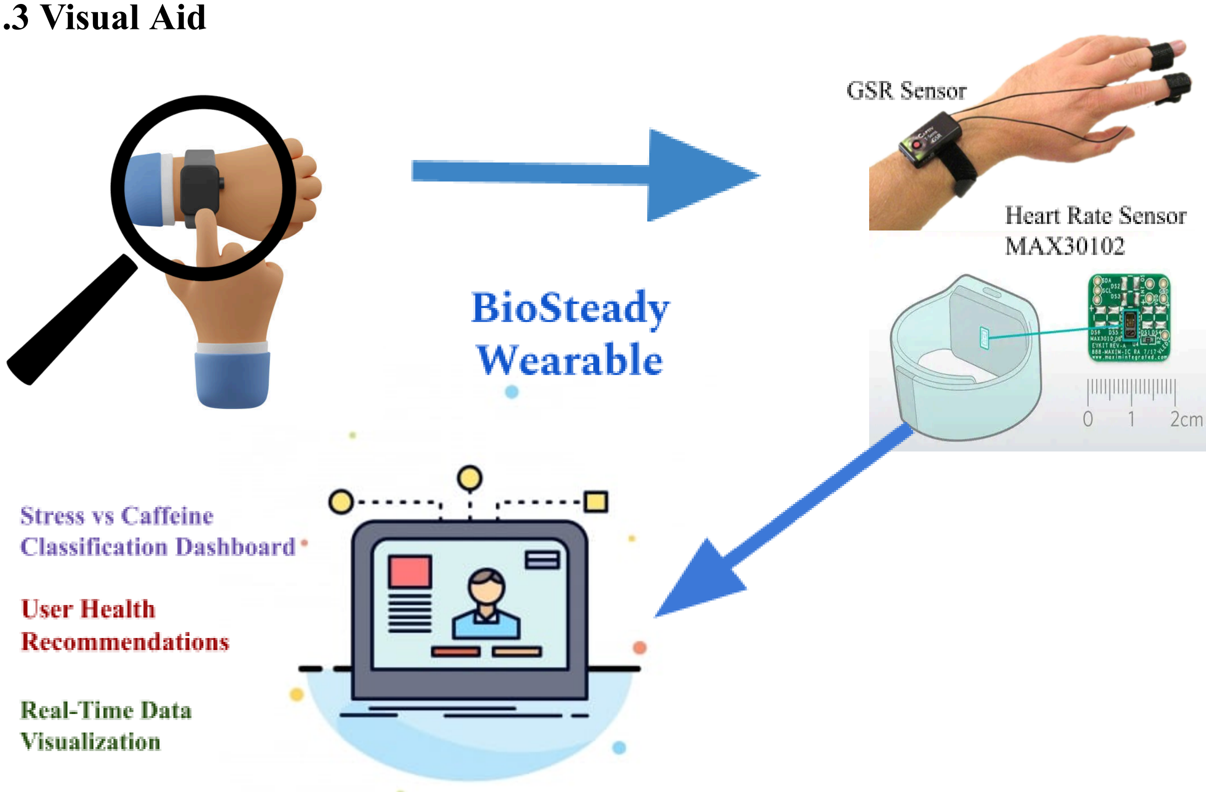

Figure 1: Visual Aid for BioSteady Project

1.4 High Level Requirements

1) Data Collection and Processing : The real-time physiological data input collected from the heart rate sensor (MAX30102) and the Elecbee GSR sensor must be processed efficiently by the microcontroller(STM32L432KC) with minimum errors to classify between stressed and caffeinated individuals correctly. The microcontroller must efficiently process this data by performing filtering to improve the data classification accuracy. We aim of a classification accuracy at around 83% when differentiating between stress-induced and caffeine-induced physiological changes.

2) Data Transmission and Communication Compatibility : The data from the microcontroller must be integrated into a web application with the right communication protocols (I2C for MAX30102 and ADC for GSR) and no significant latency upon data transmission. The data should then be processed by the microcontroller via UART and then transmitted from UART to USB to an external device, which will most likely be a computer.

3) User Interface: The web application must be able to correctly display the physiological state analysis output of the user along with effectively differentiating between stress-induced and caffeine-induced responses with actionable recommendations regarding the user's health.The UI must be at least 83% reliable using a data classification algorithm. Users must be able to receive information in a user-friendly manner where they can understand the data collected by the wearable device. The web application should include graphical visualizations of the data that is interpretable for the user.

2. DESIGN

2.1 Block Diagram

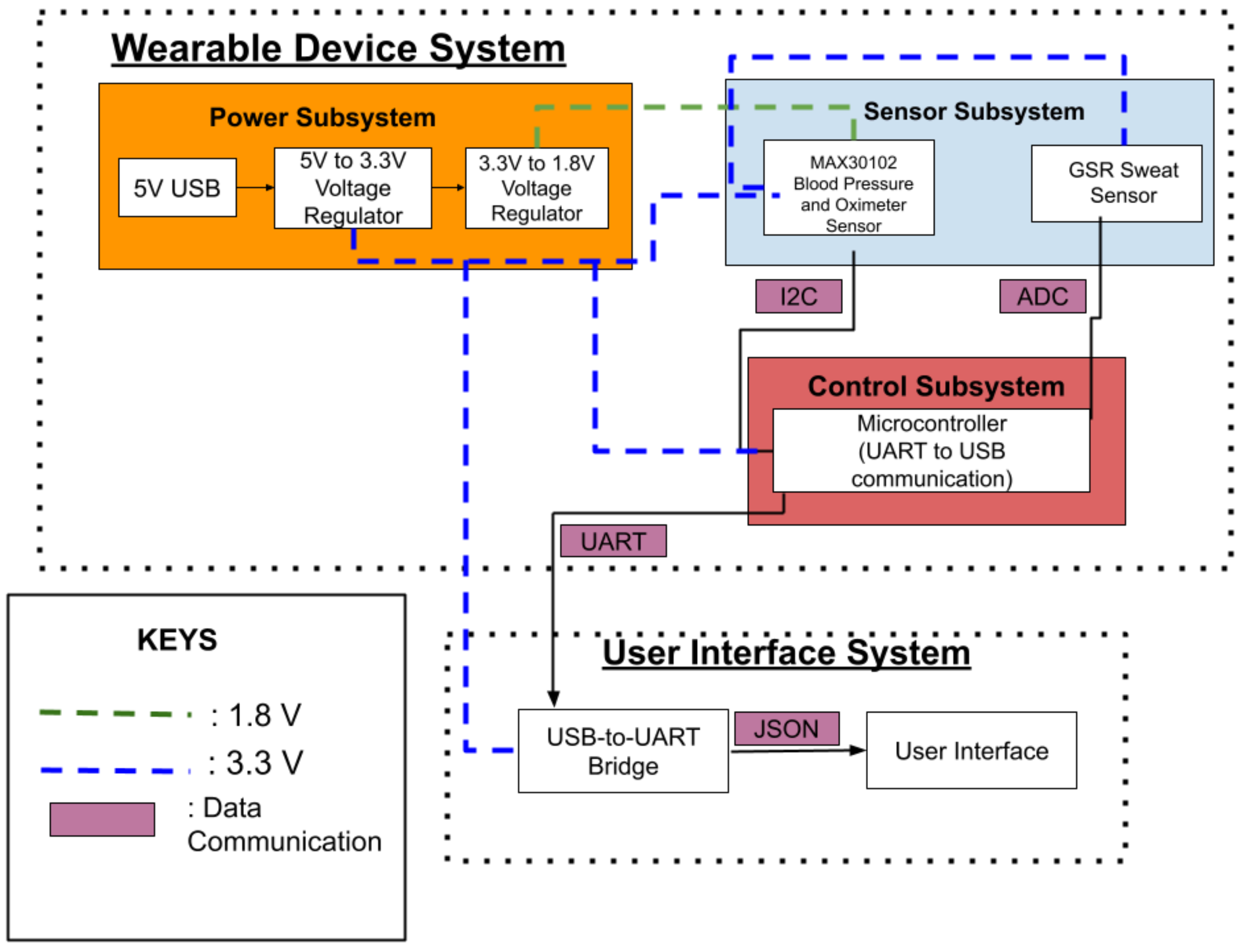

Figure 2: Block diagram for BioSteady Device

2.2 SUBSYSTEM OVERVIEW

2.2.1 Biomedical Sensing

This subsystem collects physiological data from the user such as heart rate, skin conductance and oxygen saturation levels that is compared to the users resting stats and then transmitted to the microcontroller for further analysis.

Heart Rate and Oximeter Sensor

- Sensor Name: MAX30102
- Utility: Measures heart rate, oxygen saturation levels using photoplethysmography (PPG)
- Communication: I2C

Galvanic Skin Response Sensor

- Sensor Name: Elecbee GSR Skin Sensor Module
- Utility: Measures skin conductance
- Communication: Analog voltage signal that varies with skin conductance

2.2.2 MCU and Power Management

This subsystem processes the user's physiological data and facilitates communication with external interfaces.

Microcontroller: STM32L432KC

- Interfaces: Two I2C connections for MAX30102, ADC for GSR sensor
- Power Supply: 1.71V to 3.6V for I/Os, 1.62V to 3.6V for ADCs
- Functionality: Collects sensor data and facilitates USB-to-UART communication for the the web application.

Voltage Regulators:

- LM39401-A: Converts 5V to 3.3V for MCU and sensors
- ASM1117-1.8: Converts 3.3V to 1.8V for MAX30102 core

2.2.3 Integration with Web Application

The Control Subsystem, including the MCU and USB to UART Bridge, facilitates data transmission to an external web application. This integration enables real-time visualization and analysis of the collected biomedical data, making it accessible for remote monitoring and further processing. We plan for the backend of the web application to be in python on the device to read the UART device as it provides a REST API for the frontend. For the frontend, we plan to use HTML/JSON for a user-friendly interface. Therefore, the STM32 will collect the data from the sensors, transmit it to the device via the UART-to-USB bridge, and the web application will fetch the data through the backend and visualize the data through the frontend.

2.3 SUBSYSTEM REQUIREMENTS

2.3.1 Biomedical Sensing

The MAX30102 Sensor must reliably do the following:

- Accurately measure heart rate with a precision of ±2 BPM.
- Communicate data via I2C protocol at a standard rate of 100kHz.

The GSR Sensor must reliably do the following:

- Provide analog voltage output in the range of 0–3.3V.
- Detecting changes in skin conductivity(add sensitivity?)

2.3.2 MCU and Power Management

MCU (STM32L432KC):

- Must support I2C communication for the MAX30102 and analog input for the GSR sensor.
- Process and forward sensor data(latency?)
- Operate efficiently on 3.3V to minimize power consumption.

Power Management:

- Voltage regulators must provide stable outputs of 1.8V and 5V, with a tolerance of ±5%.
- Ensure noise filtering to avoid interference with sensor measurements.

2.3.3 Integration with Web Application (need to include a UI Sketch)

USB to UART Bridge:

- Reliably transmit processed data at a baud rate of 115200 or higher.
- Support plug-and-play connectivity for seamless integration with a web application.

The Web Application Integration must:

- Receive data from the USB interface in JSON or a similar structured format.
- Support real-time visualization and analysis.

2.4 Tolerance Analysis

Tolerance analysis ensures the design functions under component, operational, and environmental variations:

I. Biomedical Sensing

MAX30102 Heart Rate Sensor:
I2C voltage must stay within 3.135V–3.465V to avoid communication errors. LED intensity variations due to aging or temperature should be compensated by MCU firmware.

Elecbee GSR Sensor:
Analog signals must limit noise to below 5%. Calibration should account for humidity and temperature changes.

II. MCU and Power Management

MCU (STM32L432KC):
Data processing must meet a 50 ms latency. Clock drift beyond ±10% must be avoided with accurate configuration.

Voltage Regulators:
Output must stay within ±5% to ensure proper operation. Regulators must operate within thermal limits to prevent failure.

III. Integration with Web Application

USB to UART Bridge:
UART communication requires timing errors under ±2%. Packet loss tolerance may need retransmission protocols.

Frontend Web Application (React, Python, Flask):
Delays up to 100 ms are acceptable for real-time analysis. The system should handle corrupted data with error logging.

3. Ethics and Safety

3.1. Ethical Concerns

Privacy and Data Security: Our project collected biometric data which can raise ethical concerns with the user's privacy and data security. We will follow the IEEE Code of Ethics Section 1.5 [3] requires that collected physiological data must be handled securely to prevent misuse by doing. We will also follow the ACM Code of Ethics section 1.6-.17 [4] by ensuring that the data collected by the Biomedical sensor subsystem is handled with the utmost privacy. Users will have full transparency on when data is collected, how data is collected, and how it is used. User data will not be shared to anywhere other than the power subsystem and the USB-to-UART system, and users will have full access to the data collected by sensors through the software component.

Team Ethics: Our team will follow the IEEE Code of Ethics Section II and III during this project to provide a safe environment for team members. We will treat each other fairly and value every person's work equally. We will strive to provide a positive work environment where collaboration is encouraged.

3.2 Safety Concerns

Electrical Safety: Since our project has sensors that require direct contact with skin, it is imperative that it is user-safety is the top priority. We will follow safety guidelines for the electrical components to mitigate potential safety hazards. We first are using sensors that operate at voltages less than or equal to 3.3V. The GSR and MAX30102 sensors operate at 3.3V and 1.8V, respectively. To ensure failure risks between parts, our PCB design will incorporate voltage regulation between the biomedical sensor subsystem and control subsystem.

FDA Medical Device Regulations: Our device is not intended for medical use or diagnosis, and users will be notified that the device should not be used as a medical device to measure any health risks. For commercial use, we will follow the Quality Management System Regulation Final Rule issued by the FDA [5].

REFERENCES

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