ECEN 403

Electrical Design Laboratory - Summer 2024

Senior Design Functional Modeling
Hemaya: Non-invasive multi-sensor wearable wristband for fatigue prevention

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Submission Date

11th June 2024

"On my honor, as an Aggie, I have neither given nor received unauthorized aid on this academic work."

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1. Introduction

Recent technical and construction advancements have resulted in skyscraper, high-rise, and bridge construction growth worldwide, increasing the demand for construction labor. This rapid expansion greatly affects how both the physical and emotional well-being of the workforce has to be taken into consideration. These issues must be addressed if fatalities and serious injuries are to be avoided. The goal of this project is to create Hemaya, a non-intrusive, lightweight multi-sensor wristband that construction workers may use to analyze fatigue. Hemaya uses the wrist to measure the vital signs of workers, such as heart rate, oxygen saturation, and tremors, as a proxy for fatigue [1].

Increased fatigue results from physical exertion, long workdays, and harsh weather conditions that construction workers face. Fatigue is a leading cause of workplace accidents and injuries despite advances in safety equipment and techniques. Research highlights that heat stress increases the risk of fatigue among workers, emphasizing the need for continued health care.[2].

Wearable healthcare technology has grown exponentially over the past 10 years. Studies show that wearable technology can effectively manage fatigue by continuously monitoring medical symptoms. Studies such as "Fatigue Monitoring Through Wearables: A State-of-the-Art Review" highlight the importance of fatigue monitoring for worker safety and health. Wearable technology can track how fatigue affects physical and mental performance, increasing the likelihood of accidents and reducing productivity. Effective application of current solutions is hampered by the fact that they are usually analyzed for short periods of time under controlled conditions [3].

To overcome these obstacles, this study presents real-time fatigue monitoring by integrating sensors monitoring heart rate, hand tremor, and oxygen saturation. This innovative strategy aims to establish an effective and safe working environment by enhancing protection, lowering the frequency of accidents, and enhancing employee well-being. To ensure proper physical examination, the proposed belt integrates sensors to detect oxygen saturation, heart rate, and hand tremor that overcomes existing barriers. To give a real-time fatigue diagnosis, the data from these sensors will be analyzed using a machine learning algorithm that runs on an Arduino Cloud. The companion app provides instant access to collected data, makes it easier to detect and treat fatigue, and allows for quick action when needed.

Multiple hardware components, data processing, analytics and machine learning integration are all part of the development. Arduino Uno R4 Wi-Fi microcontroller is integrated with hardware components like Triaxial Accelerometer ADXL335 and Pulse Oximeter Biosensor Heart Rate Monitor MAX30102. Software developed with Arduino IDE will monitor power consumption and optimize sensor performance. The Arduino Uno R4 Wi-Fi module will enable real-time data transfer while processing and analyzing the data collected by the sensors. [4].

The project is dealing with several other challenges, such as optimizing battery life, connectivity issues, severe weather conditions in Qatar, and delayed Institutional Review Board (IRB) clearances.

2. Upper-Level Functional Modeling

Figure 1 illustrates the upper functional modeling diagram, which outlines a system designed to monitor and evaluate fatigue levels. The prime components of the designed system consist of two sensors. The first sensor is the pulse oximeter MAX30102, which measures the heart rate and the SpO2 (blood oxygen saturation). The second sensor is the ADXL335 accelerometer, which measures the tremor levels. The sensors and the 6V rechargeable battery will be connected to the Arduino Uno R4 Wi-Fi microcontroller to collect real-time data and upload them to the cloud for further analysis. This is where the Machine Learning (ML) part comes into play. The ML model will evaluate the data and compare it to the predetermined threshold set for each of the parameters used. If the SpO2 level is below 95%, the model will indicate fatigue. In addition, for the heart rate, if the threshold is above 100 bpm, it will indicate fatigue. Similarly, with the tremor, if it is detected to be greater than 12 Hz, the model will flag fatigue. Furthermore, the goal of creating a user-friendly interface using a variety of tools and screen sizes will be a key strength in creating a flexible mobile application for real-time fatigue monitoring. The application will provide charts, graphs and visualizations of the analysis of the fatigue levels detected. An alarm system will also be integrated with the mobile application to send an alert to immediately notify the supervisor in case of any fatigue detections.

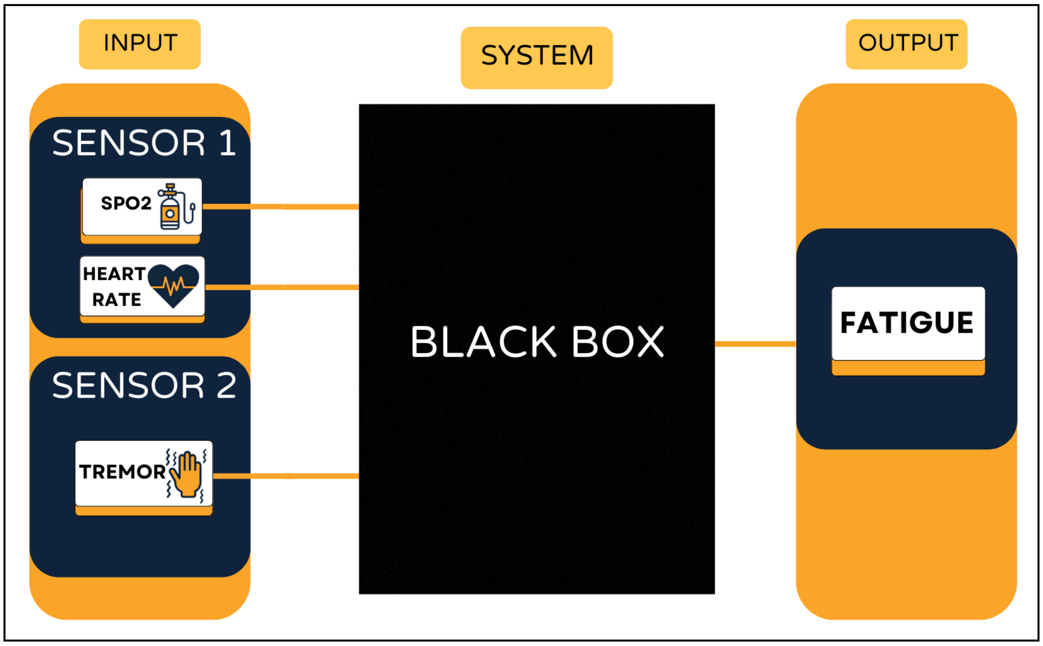

Figure 1: Upper-Level Functional Modeling Diagram

3. Detailed Functional Modeling

3.1 Full Functional Model Diagram and Summary

The detailed functional model is presented in Figure 2. The diagram of the model for the Hemaya project illustrates a system created to oversee and address worker fatigue by combining sensor technology data analysis and artificial intelligence. The system is structured around five functions (Figure 3), each essential to its effectiveness. An explanation of each function is provided below.

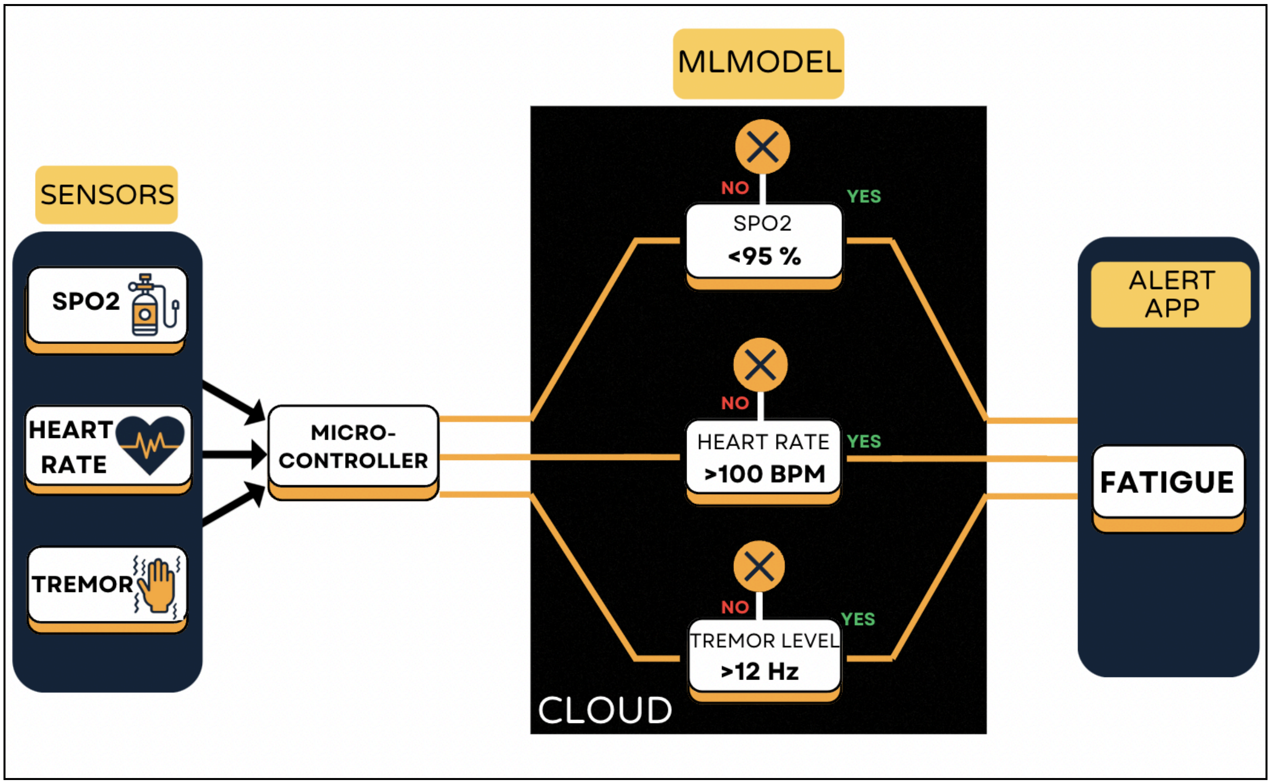

Figure 2: Detailed Functional Model

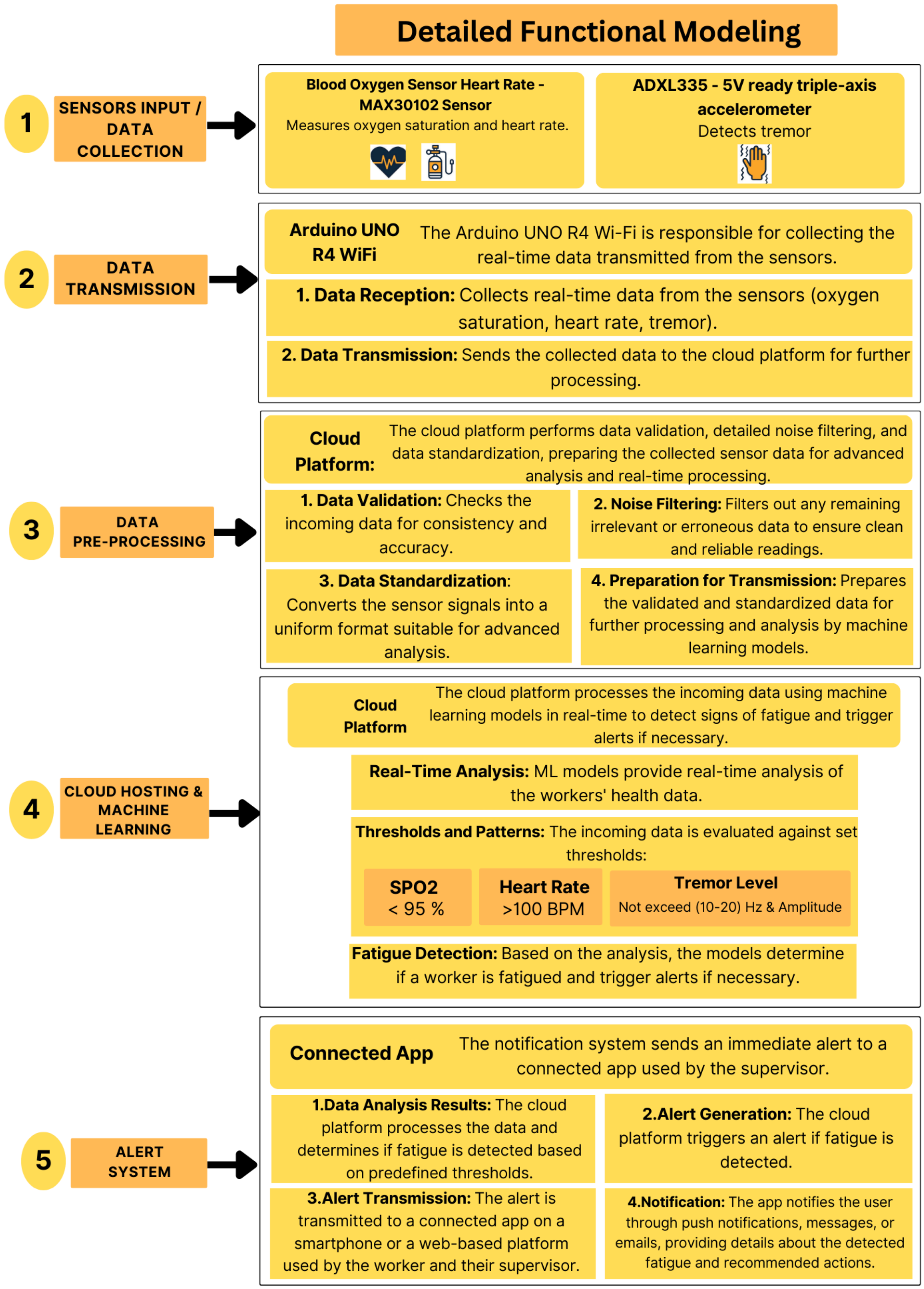

Figure 3: Functions Detailed Description

3.2 Function 1: Sensors Input / Data Collection

This process includes utilizing sensors to gather information from employees. The sensors referenced are the Blood Oxygen Sensor Heart Rate Click GY MAX30102 Sensor, which can measure blood oxygen saturation and heart rate, and the ADXL335. 5V ready triple-axis accelerometer, which detects tremors or involuntary movements indicating fatigue.

3.3 Function 2: Data Transmission

The Arduino Uno R4 WiFi microcontroller functions as the central hub for collecting data from the sensors. It acquires and organizes sensor data, converting raw readings into usable values such as oxygen saturation percentages. This preparation ensures that the data is ready for further analysis and processing.

3.4 Function 3: Data Pre-Processing

After gathering the data, the Cloud Platform continues pre-processing it. This includes verifying the data to confirm its reliability, preparing it to eliminate any irregularities, and removing any noise to guarantee the data's precision. This stage is essential to ensure the analysis's dependability.

3.5 Function 4: Cloud hosting and machine learning

Within the cloud platform, machine learning models will analyze the data to detect signs of fatigue. These models will learn to recognize fatigue by examining patterns in oxygen saturation, heart rate, and tremor levels. For example, a drop in oxygen saturation below 95% may indicate fatigue in the worker. The threshold for heart rate will be calculated based on the user's age [5]. A significant increase in heart rate during strenuous activity, approaching or surpassing their age-adjusted threshold, could indicate strain and potential fatigue [6]. Additionally, tremor levels, considering both amplitude and frequency, exceeding 10-20 Hz may indicate muscle tiredness or neurological concerns [7].

3.6 Function 5: Alert System

The last feature is the system, which activates when the machine learning models identify fatigue using set limits. Notifications are transmitted via a linked app to both the worker and the supervisor. This quick alert enables action to avoid accidents or additional health concerns caused by fatigue.

4. Analysis and Evaluation of Assignment

The assignment exemplifies a thorough strategy for tackling the important problem of worker weariness in the construction sector. By emphasizing the growing need for construction workers because of worldwide improvements in engineering and design, the introduction successfully sets the scene [8]. Workers' physical and mental health have been found to suffer because of this fast-paced work environment [9]. To ensure worker safety and well-being, the introduction, therefore, emphasizes the vital need for creative methods to detect and manage tiredness.

Additionally, the introduction highlights the importance of scientific and technological concepts in engineering, not only for the purpose of planning and building buildings but also for the purpose of protecting the workers who create them [10]. The project's importance and urgency in the contemporary industrial setting are highlighted by this dual focus. The research intends to solve these urgent problems by recommending a non-invasive multi-sensor wearable wristband that can monitor vital physiological indicators in real-time, including heart rate, oxygen saturation, and tremor [11]. This proactive strategy demonstrates a careful integration of technical innovation with occupational health and safety requirements, with the goal of preventing accidents and improving the general health of construction workers.
The project's aims are in line with more general objectives to support the construction industry's transition to a safer and more productive work environment. This gives the other portions of the assignment a strong basis.

We have identified and applied the essential design changes or improvements by closely analyzing our non-invasive multi-sensor wearable wristband system after working through the functional modeling assignment. The systematic division of the execution process into primary and supplementary functions makes it easier to error-check related components together before integration. This systematic technique simplifies the development process while improving each module's dependability. Through a thorough analysis of every element, we have ensured that our design is reliable and effective. This evaluation will help us improve our prototype and finally accomplish our objective of developing a wearable wristband that effectively decreases fatigue among construction workers.

5. Conclusion

This report has enabled a thorough assessment of every sub function in our system, thereby simplifying the implementation of required improvements or changes to the design. By breaking down the implementation process into primary functions and subfunctions, we can quickly find and fix problems in related parts before they are integrated. This methodical approach guarantees the dependability of each component while also encouraging effortless integration, which eventually results in a more reliable and effective system. Furthermore, the evaluation's insights will direct later stages of development, guaranteeing ongoing enhancement and optimization.

6. References

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