**Environmental Stress Monitoring System (ESMS)**

Media Management
Semester Project Report

**Group Name: Team ESMS**

**Group Members:**
Dipendra Thapa
Pritam Pramanik
Shokhjahon Kodirov

**University: Deggendorf Institute of Technology**
European Campus Rottal-Inn

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## 1. Introduction – Physiological Problem

Stress is a complicated physiological phenomenon which can occur when the human body recognizes demands both internally and externally which can work as challenges to its ability to manage homeostasis. Stress can be viewed as a purely physiological phenomenon because it involves the autonomic nervous system, which is stimulated by the sympathetic nervous system with reactions such as high heart rate, high blood pressure, and hormonal changes. Stress is often viewed as a purely psychological phenomenon because it is associated with reactions which can be measured through biosignals.

Nature has a profound influence on the onset of or the enhancement of physiological reactions associated with the stress response. Extreme temperatures can lead to impaired thermoregulation; the increased load on the circulatory system will have the physiological effect of forcing the heart to work under increased effort in order to sustain a constant body temperature. High humidity concentration makes the process of evaporatory cooling less efficient in the body’s sweating process; hence, increased physiological effort will be exerted. Noise exposure has significant effects on the physiological response associated with the onset of a stress response in the body; this has been gauged by the increased stimulation of the associated neural paths resulting in the augmentation of heart rate and the level of stress hormones in the body’s physiological process.

Heart rate is an universally recognized physiological parameter reflecting the state of stress because heart rate rapidly changes in accordance with the state of autonomic nervous system activation. An increase in heart rate is often linked to sympathetic activation, which is often induced in stressful environments. While heart rate does not give an integrated reflection of the state of stress, it acts as an ideal proxy parameter because heart rate can be measured continuously in real time. This parameter, when measured in relation to some intrinsic property of the environment, enables correlations to be made.

The motivation of the ESMS is to develop a practical, data-driven system linking environmental parameters to physiological responses for identifying potentially stressful environments. The project is not for medical diagnosis, but rather for continuous monitoring and visualization to enable awareness, prevention, and optimization of environmental conditions. The core concept of ESMS strives to provide an interdisciplinary integration of environmental sensors with heart rate and motion detection sensors combined with sensor technology and software systems for a better understanding and management of environmental stress.

## 2. Technical Solution and Architecture

The proposed Environmental Stress Monitoring System (ESMS) is modeled as a scalable and data-centric system which encompasses environmental sensors, heart rate sensors, PIR motion sensors, Rust-programmed backends, and frontend viewing interfaces. The system has been modeled using a data-centric paradigm where raw environment knowledge is extracted directly from sensors, processed on the backend system, and stored in the Redis database for real-time analysis and MySQL storage for future analysis (Figure 1). As can be clearly observed in Figure 1, the raw data extracted directly from sensors seamlessly flows into the back-end and database systems leading to final viewing displays on the frontend viewing displays.

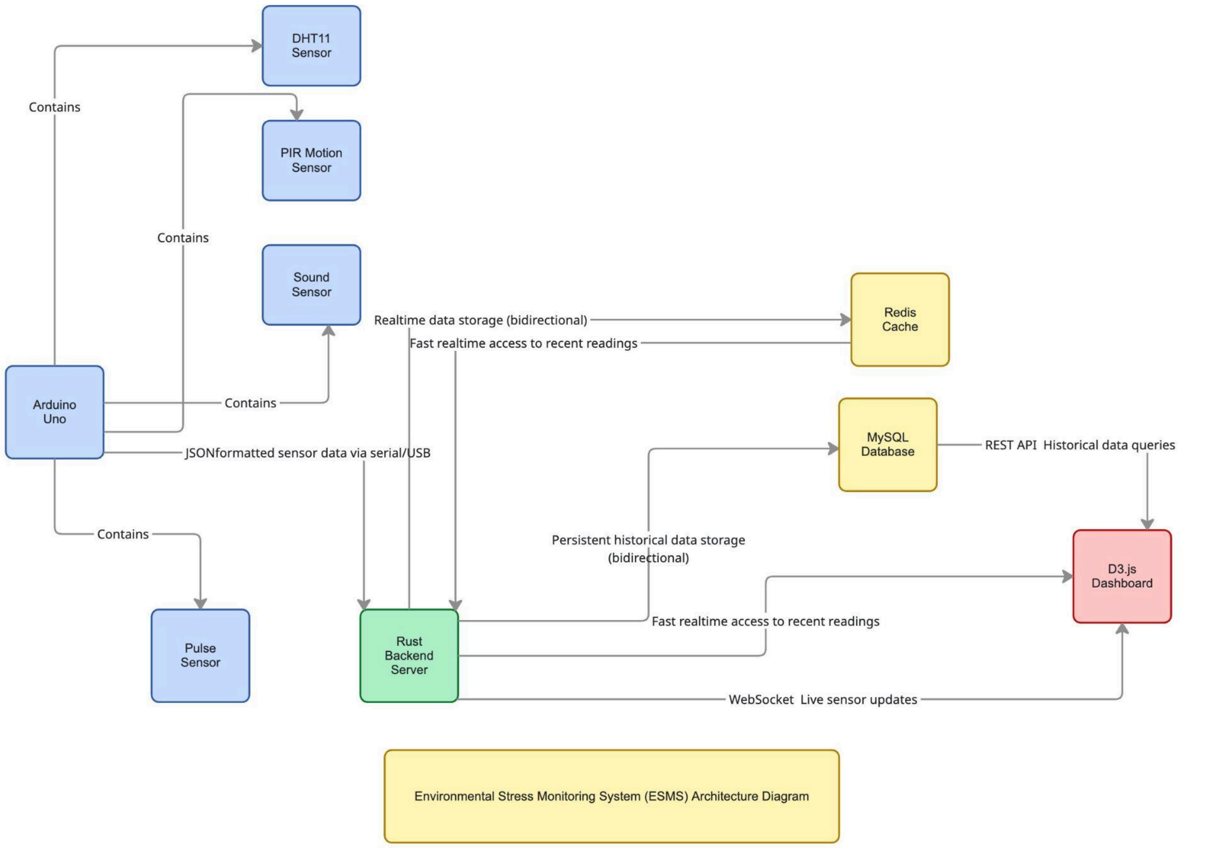


Figure 1: System architecture of ESMS showing sensors, backend (Rust), Redis, MySQL, and frontend visualization(D3.js).

From a hardware perspective, ESMS makes use of environmental sensors such as temperature, humidity, and noise level sensors. The sensors offer continuous quantified data on the levels of the factors that are known to affect physiological stress. Additionally, the heart rate sensor will be employed to record pulse rates. This remains the core physiological component of the system. To make the system contextually conscious, the Passive Infrared (PIR) motion sensor shall be employed. The motion detector has the capability of detecting the presence of human beings as well as the movement of the population. This helps the system to recognize whether the periods are active or inactive. This plays a core role when the heart rate data is being interpreted. Physical exercises will boost heart rate irrespective of the stress.

The backend of ESMS is developed using Rust because of its performance-oriented nature, memory safety, and concurrency characteristics. The backend is used for handling ingestions, validations, processing, and coordination of various components of the system. Data from sensors is fetched using REST APIs designed and developed as a functionality of the backend of ESMS. The designed APIs help in proper communication between sources and processing components with consistency and reliability of data exchange.

Redis is employed as an in-memory database solution for buffering real-time data as well as providing efficient real-time data access. The sensor values are buffered in Redis to enable low-latency operations such as real-time stress indicators. Redis is efficient in handling the high-frequency updates coming from sensors and enables scalability without needing direct storage solutions. This is especially important in real-time monitoring systems where real-time response is one of the important factors.

For the purpose of storing, a relational database management system named MySQL is employed. The structured data retrieved from the sensor, aggregated, and historical data are stored in the MySQL system for future analysis and generation of reports. The advantage of using the relational database management system is that the integrity of the data is assured, complex queries are allowed, and future modifications, for example, trends and the implementation of third-party analytics software, are feasible. The hybrid system of storing data using Redis and MySQL is employed.

The data transmission process in ESMS occurs from the sensor level, from which environment, physiology, and motion data is collected. The data is transmitted to the Rust backend server via REST APIs and then verified and stored in Redis. The data that is of interest is stored in the MySQL database for long-term retention. The frontend displays the processed data from the backend and provides interactive visual representations for the user to analyze the relationships between the environment, the states of motion, and heart rate.

Scalability and reliability were some of the primary factors that came into play in the design of the system. The design of the backend system is horizontally scalable because the stateless API servers can be replicated whenever the need arises. Redis dampens the load on the database because the system relies on Redis for the processing of real-time queries. On the other hand, the use of MySQL guarantees a reliable form of storage of information in the long run. On the concept of complexity management, ESMS is an appropriate system that brings forth the idea of how different components in a distributed system can be.

For improving usability and system interpretability, care has been taken to design a user-friendly interface on the frontend side of the system. Data display through real-time dashboards using graphical representations like line graphs, bar graphs, and stress indicator panels is designed in such a way that dynamic analysis of correlations between environmental factors, heartbeat rate, and motion activity is reflected accurately on these dashboards. The system is designed such that users are allowed data filtering characteristics of time period, sensor-type, or activity level analysis, which is quite helpful for focused analysis of particular scenarios. Furthermore, triggering of alert systems is possible for users concerning predefined thresholds of environmental or physiological factors, which is helpful for proactive systems. The design principles of both backend and frontend are such that there is seamless inclusion of novel sensors or analysis capabilities with minimal system overhead, which further adds scalability and flexibility to ESMS such that ESMS is a system adaptable and evolving with changing requirements of users and paving way for future research on smart stress models or adaptive environments.

## 3. Results and Analysis incl. Interpretation

There were obvious correlations between environmental factors and heart rate activity for all of these scenarios. Regions of high temperature were typically related to overall high heart rates, especially when high levels of humidity were also present. This is a natural correlation between factors, since a high temperature would require more cardiovascular activity related to thermoregulation. High levels of ambient noise were typically related to peaks of high heart rate activity related to stress responses.

The addition of the PIR motion sensor allowed for better interpretation of physiologic readings. While during times of detected motion, physiologic readings of increased heart rate may have been due to physical activity rather than environmental factors. Conversely, physiologic readings of increased heart rate during times of little to no motion were more likely due to environmental factors of heat, humidity, and/or noise rather than to said factors as the direct cause.

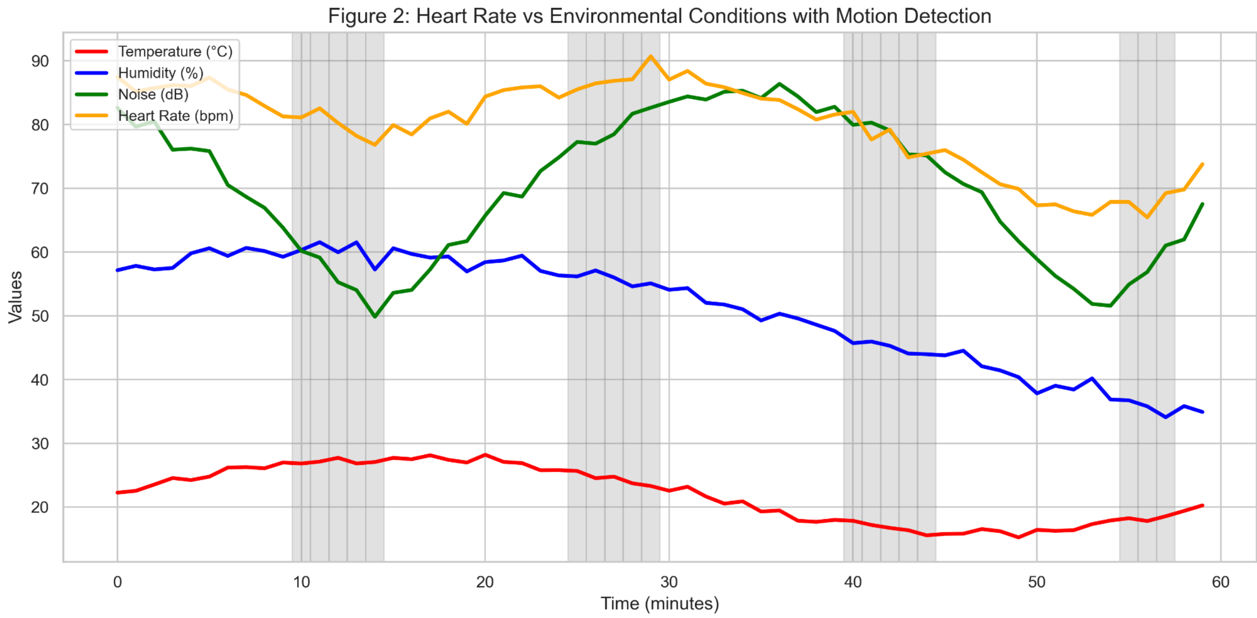


Figure 2: Heart Rate vs Environmental Conditions with Motion Detection

These are illustrated in Figure 2 above, which shows heart rate, in addition to other factors, which indicate heart rate when there are high levels of temperature and noise, with the shades representing PIR detected motion. This figure shows that when there are high temperatures and noise, there are higher heart rates, and that the shades, which are detected by PIR, indicate that there are motions.

From a perspective of stress interpretation, the correlations suggest that a hypothesis concerning an unfavorable environment affecting stress responses to a certain extent is valid. Heart rate alone cannot measure the extent of stress exposure, but a combination of data parameters of the environment, motion, and stress responses can give an approximation of stress exposure in those environments.

However, there are some limitations to the system. Individual differences were not considered for fitness, heart rate, and stress response, which might impact generalization. Further, the short observation time and the imperfections of the sensor calibration may add some randomness to the results. Despite this, the results demonstrate the technical and conceptual validity of the ESMS method.

## 4. Individual Responsibility, Learnings, and Challenges

The personal input provided for the ESMS project was centered on backend development. The development of the backend component of the project using Rust programming and the overall development of REST APIs for the processing and ingestion of sensor data was my responsibility. The ingestion and processing of data between the Redis and MySQL databases were supposed to be carried out in a way that enables the efficient real-time data processing and ensures successful data storing.

This project has given me numerous learnings. It has given me an in-depth knowledge of how Rust supports concurrency and its memory safety capabilities. It has also given me hands-on experience of working with Redis and MySQL databases. The project gave me an understanding of real-time data and its handling. The project has given me a conceptual understanding of how physiological parameters can be made context-dependent with help of environmental and motion sensors.

During the development process, a couple of challenges had to be dealt with. The use of Rust's rigid compiler and its concept of ownership proved quite a challenge during the design and debugging process, especially when dealing with asynchronous data. Integration of real-time streams of data and the storage system had to be carefully planned to prevent the possibility of data inconsistency. From the systems point of view, the challenge of dealing with the complexities of several different components suggested the need for proper communication.

The project overall yielded great experience in system design by interdisciplinarity, such as reinforcement of backend reliability, scalability, and clarity in the complex innovation project.

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