Occupational Health Monitoring and Alert System

BE Senior Design

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UTA College of Engineering Innovation Day — April 18, 2023

Executive Summary

Firefighters are regularly exposed to occupational hazards, including serious health risks due to heat exhaustion and overexertion in the line of duty. However, the symptoms of these conditions are difficult to identify, and firefighter culture may discourage self-reporting symptoms. The goal of this project is to design a non-invasive system consisting of two devices that will monitor heart rate (HR), skin temperature (Tskin), and estimate core body temperature (Tcore), equipped with LEDs for alerting the wearer and others around when the firefighter is experiencing symptoms of heat exhaustion or overexertion. This design could provide department-wide, standardized biometric monitoring equipment so that all-day on-duty insight on the health of every firefighter is known, preventing injury and circumventing the ability for the firefighters to hide symptoms.

Background

- The Arlington Fire Department expressed a need for a device that would improve health and safety standards while providing critical insight into the health of firefighters throughout the department. There is currently no device that can provide monitoring and alerting for fire departments.
- The most prominent causes of injury and illness for firefighters in the U.S. are over-exertion and heat exhaustion. In 2019, 56% of on-duty firefighter deaths were caused by heart attacks and heat exhaustion related illness [1].
- Firefighters hiding symptoms of heat exhaustion or overexertion is a big problem in the force and exacerbates the already high health risks of their work. This not only endangers themselves, but also puts others at risk in case of a hazardous situation, such as falling unconscious during a structural fire.

Figure 1. Fallen firefighter [2]

Conceptual Design Phase

The project's physical and functional requirements (Table 1) were developed in collaboration with the Arlington Fire Department. While initial requirements for the wearable device housing included water and heat resistance and durability, these were sacrificed to prioritize a robust and accurate real-time biometric data processing and alert system with the idea to aim for those requirements in the future.

Table 1. Physical and Functional Requirements

Physical Requirements	Functional Requirements
Cohesive with existing gear	Measure heart rate (HR) and skin temperature (Tskin)
Wearable and ergonomic	Estimate core body temperature (Tcore)
Small and Lightweight	Real-time data processing
Easily accessible housing	Visual LED alert system

Initially, we planned to integrate our device and sensors with firefighting turnout gear for use during fire scenes or when the gear was worn. However, research showed that many fatalities and hospitalizations occurred after such scenes, indicating a need for continuous monitoring and alerting. To address this, we aimed to create a fully modular device that could accommodate different configurations and monitor firefighters all day for any serious condition.

Detailed Design Phase

We spent most of our design phase creating a robust real-time signal processing system using C++ with an ARM microcontroller.

Heart rate – using a max30102 PPG sensor we developed algorithms to filter out noise and motion artifacts for consistent HR readings during exercise.

Temperature – We chose a thermistor for Tskin measurement due to its accuracy and fast response time, critical for real-time monitoring in hazardous jobs. Our Tcore estimation algorithm requires only skin temperature and heart rate inputs, based on research showing that this minimum input model is powerful for estimating Tcore compared to rectal temperature and other models (see Figure 2).

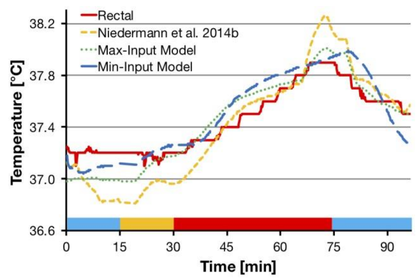

Figure 2. Comparisons of measured rectal temperature (50% HR max cycling intensity, protective firefighter gear) [3]

Device Ergonomics – Using gear provided by the fire department, we studied the best locations for monitoring. The wrist and forehead have blood vessels close to the skin, making them suitable for PPG sensors. These areas are less prone to motion artifacts and are convenient for wearing sensors, including the helmet which is worn during various duties. The helmet contains a control unit under the back of the helmet (not touching the body), the small sensor unit is attached to the inner lining of the helmet resting tightly and comfortably against the forehead.

Figure 3. Helmet configuration prototype

Analysis and Testing

We conducted trials of our prototype and compared the baseline and exercise biometrics to ECG, temperature transducers, and a fever thermometer that also estimates Tcore.

1 way ANOVA tests were run to compare the data collected from our device to lab grade measurement equipment and found no significant differences between the data with a p-value>0.05.

Key Take Aways:

- Our PPG Sensor and thermistor accurately measured Heart Rate and Skin Temperature compared to lab grade measurement equipment
- Our microcontroller processed this data real time to provide an accurate Tcore estimation

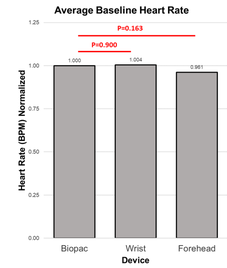

Figure 4. Average heart rate data from Biopac compared to our wrist and forehead devices during baseline recording

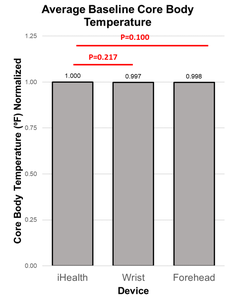

Figure 5. Average core body temperature estimation from Biopac compared to our wrist and forehead devices during baseline recording

Conclusions

We presented our final device performance to Arlington Fire Department, and they were impressed with our ability to accomplish the core technologies they expressed needs for in our initial meetings and look forward to future development.

In future works, we want to develop a fully wireless system with a control center that can allow a variety of device placements with a cloud component that will allow commanding officers to view real-time health data on a tablet of all firefighters. We also plan to include additional metrics such as evaluation of anxiety levels. Firefighters are regularly exposed to distressing and high-stress situations. Anxiety can have detrimental effects on their mental health and job performance, potentially leading to burnout, post-traumatic stress disorder (PTSD) and other serious conditions.

We are thankful to the Arlington Fire Department for hosting our team leader to develop this idea over an immersive integrative experience last summer. We extend our gratitude to the Health and Safety Officer for their mentorship and guidance throughout the project. With their help, we gained field experience and developed a product that meets the unique needs of the fire department. Our product is designed with the intent to protect those who protect us.

References

[1] U.S. Fire Administration, Department of Homeland Security. Firefighter Fatalities in the United States in 2019. October 2020. Usfa.fema.gov

[2] John G. Alexander, 2013. How to Assess and Treat Injured Firefighters. EMSworld. https://www.hmpgloballearningnetwork.com/site/emsworld/article/10934759/how-assess-and-treat-injured-firefighters [image]

[3] Eggenberger P, MacRae BA, Kemp S, Bürgisser M, Rossi RM, Annaheim S. Prediction of Core Body Temperature Based on Skin Temperature, Heat Flux, and Heart Rate Under Different Exercise and Clothing Conditions in the Heat in Young Adult Males. Front Physiol. 2018. doi: 10.3389/fphys.2018.01780