Designing a Smart Helmet for Wildland Firefighters to Avoid Dehydration by Monitoring Bio-signals

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ABSTRACT

Smart Helmet is a new wearable device to monitor wildland firefighters' real-time bio-signal data and alert potential health issues, i.e., dehydration. In this paper, we applied the human-centered design method to develop Smart Helmet for firefighters. We initially conducted multiple rounds of primary research to collect user needs and the deployment constraints by interviewing 80 firefighters. Targeted on dehydration caused by heat exhaustion and overexertion, we developed a smart helmet prototype, named FireWorks, with an array of sensors collecting the firefighter's bio-signals, including body temperature, heart rate, and motions. When abnormal bio-signal levels are detected, the alert system will notify the firefighter and their supervisor. The notification is achieved by an on-device algorithm that predicts imminent health risks. Further, we designed a mobile application to display real-time and historical bio-signal data as well as alert users about potential dehydration issues. In the end, we ran user evaluation studies and iterated the prototype based on user feedback, and we ran the functional evaluation to make sure all the implemented functions work properly.

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CCS CONCEPTS

• **Human-centered computing** → **Interaction devices**; • **Hardware** → *Wireless devices.*

KEYWORDS

Firefighting, wearable, bio-signal, health sensing, sensor, dehydration

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1 INTRODUCTION

Dehydration is a frequent problem for wildland firefighters during their deployment in the field. A series of heat-related illnesses such as heat cramps, heat exhaustion, and heatstroke [15] affect the health and wellness of wildland firefighters. This paper describes how we designed a smart helmet to include a sensor array, an alert system, and a corresponding mobile app to distinguish different scenarios in the field. We also describe how we run different rounds of user evaluation and what functions we add to improve the user experience. User experience is the core of our design, whether we are developing the helmet, implementing the App, or building the original algorithm. We want to use this paper to demonstrate how

we build this human-centered smart helmet to protect the wildland firefighters and improve the user experience. Finally, we described the functional testing progress and feedback at the end of the paper to demonstrate that all of the implemented functions work and all of the algorithm's events can be triggered.

2 BACKGROUND AND RELATED WORK

2.1 Wildland Firefighter Deploying

Wildland firefighters working in extreme conditions with consecutive shifts face multiple stressors, such as woodsmoke exposure [1, 3], heat[2, 13], sleep disruption[2, 7] and so on. These stressors could lead to lifelong asthma [1], impact their cognitive performance and sometimes [2], even cause death. Since 2000, 313 wildland firefighters have lost their lives on the field [5], and 54% of them were caused by overexertion under hot and challenging conditions [20]. Wildland firefighting typically requires longer (12–16+ hour days) and arduous work shifts (4,000–6,000 calories expended a day) for up to 14 continuous days [4], which would increase the risk of getting heat overexertion. A crew supervisor's primary responsibility is to lead their crew in the safe and effective completion of assigned work [16]. They need to work on the field alongside their assigned group of wildland firefighters during deployment. The current method to detect heat exhaustion and overexertion incidents is by human observation, which can be too slow and inaccurate in assessing different heat-related conditions. As researchers suggest that early management of dangerous situations and timely rest can help firefighters work safely and efficiently[7, 13, 19], we proposed a set of health monitor and feedback systems to help both firefighters and supervisors manage their health condition.

2.2 Relevant health monitor devices

Kremens, Faulring and Phillips [12] developed a portable device that can monitor the external environment (temperature, carbon monoxide concentration, GPS location) and internal state (body temperature, heart rate and movement) of the firefighter, and they use LED lamps and sound as alerting signals. This device needs an external antenna for data transmitting, and the main part of the device is put in the pocket or somewhere else while the alert and switch part should be put on the shoulder of firefighters. However, they did not indicate where they put the sensors and how they deal with the data. ProeTEX [17], an European Integrated Project aims to monitor multiple biosignals of rescuers, such as ECG, internal and external temperature, heat flux and even respiratory rhythms. The members of the project work on each parameter separately and most of their form factors are jacket or T-shirt. As firefighters already take many equipment while deploying, some researchers [8] think we should enhance the existing pieces that firefighters can easily bring and maintain. Hence, Helon [8] and Jeong et al. [10] both came with the idea of equipping a firefighter's helmet with cameras for environmental assessment.

3 METHOD AND RESULTS

We researched the placement of wearable devices and the alert system to find the solutions that can work under a variety of deployment environments and understand the user needs. We used the findings to analyze various iterations of prototypes, and the user evaluation results helped us generate the final solution.

3.1 Wearable Device Research Method and Results

We interviewed 15 crew supervisors and surveyed 80 wildland firefighters to understand their needs, the environmental work conditions, and design requirements to use in the development of a technology solution that wildland firefighters and their crew supervisors would adopt and use. Eight questions for the interview and 12 questions for the survey were developed. The interview and survey can be roughly divided into three sections: (1) Deployment Environment, (2) Wearable Device, and (3) Communication Flow.

The **questions** included: (1) What equipment and devices do wildland firefighters need to bring to the field? (2) What kind of wearable devices and location for placement on their bodies are more acceptable for use during the deployment? and (3) How do wildland firefighters communicate with each other in the field?

The **results** included: (1) Each wildland firefighter needs to carry over 60 lbs in weight during their deployment, (2) Sometimes there is no Wi-Fi or cellular connection in the field. They have to use a separate wireless communications platform called FirstNet by AT&T to get wireless service. (3) Radio is their primary method to communicate with each other, but sometimes radio loses messages, and (4) Watches and helmets are the two most practical form factors for wearable devices in the field.

The findings from our surveys influenced the design decision to develop a Smart Helmet wearable device since 70% of the wildland firefighters are not in the habit of wearing a watch in the field, but all of them must wear a helmet during their deployment in the field. Bluetooth Low Energy (BLE) was selected as the communication protocol to transmit data between the helmet and the app since it does not require large amounts of data and can run on battery power for a long time at a low cost [18].

3.2 Alert System Research Method and Results

To research the appropriate method to implement the alert system, we conducted medical expert interviews with three medical experts. One of the medical experts is researching using skin temperature and heart rate to estimate physiological strain during exercise in the heat, which is similar to our project. We prepared 8-10 interview questions in three sections: (1) Health Data Changes, (2) Physiological Strain Index, and (3) Sensors. During each interview, one team member led the interview, and another team member took notes and recorded the interview.

The **questions** included: (1) How will the heart rate and skin temperature on the forehead change when heat-related illness becomes severe? and (2) How can we use the Physiological Strain Index to estimate people's health status?

The **interview results** included: (1) The forehead skin temperature will keep increasing when heat-related illness becomes more severe. The skin temperature will rise slower when people experience heat exhaustion due to an increase in sweat on the forehead, (2) The Physiological Strain Index is more suited for measuring skin temperature and not core temperature, and (3) Monitoring heart rate on the head is challenging, but industry-level heart rate

and crew supervisors can be immediately notified when the Helmet detects abnormal health data. We have made different versions of prototypes and update lots of functions based on the primary research and user evaluation to optimize the users' experience. Overall, we have shown that the Smart Helmet has the potential to save more time for the users to diagnose heat-related illnesses in the field and improve the overall health of the wildland firefighters in the field. Crew supervisors evaluated the Smart Helmet and determined that it could assist them in monitoring the health of wildland firefighters and save lives. We are further developing this product in the context of user experience for both the crew supervisors and the wildland firefighters.

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