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Real-Time Emergency Communication System for HAZMAT Incidents (REaCH) - Phase I

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Table of Contents

Disclaimer vii
Abstract viii
Chapter 1 Introduction 1
1.1 Organization of the Report 1
1.2 Background 1
1.3 Project Goal 3
Chapter 2 Literature Review 5
2.1 Sensor Technologies 5
2.1.1 Wearable Technology/Wearable Devices 5
2.1.2 Health Monitoring Sensors 7
2.1.2.1 Telemetry pill 7
2.1.2.2 Zero – Heat Flux sensor 7
2.1.2.3 AliveCor's Kardiaband 8
2.1.2.4 LilyPad Temperature Sensor 8
2.1.2.5 Hot Dot Alert Patch by OSHA 8
2.1.2.6 Zephyr 8
2.1.2.7 Drager – TCORE 9
2.1.2.8 Polar OH1 9
2.1.2.9 Pulse sensor 9
2.1.2.10 Texas Instruments CC2650 Sensortag 10
2.1.2.11 CHASE LifeTech FR 10
Chapter 3 Research Approach and Methods 11
3.1 Focus Groups 11
3.1.1 Omaha Fire Department Special Operations 11
3.1.2 HAZMAT Haulers Interviews 14
3.2 Integrated Sensor Dashboard Design 15
3.3 First Responders' Wearable Technology Survey 16
3.4 Other Notable Activities 17
Chapter 4 Future Work 19
References 20
Appendix A Sample use case diagram and user scenarios. 22
Appendix B Agile methods flowchart. 26
Appendix C Survey 27
Appendix D Testing Environmental Sensors to Reduce Heat Ailments among First Responders 33
Appendix E Visualize to Realize: Improving Safety of First Responders 34

List of Figures

Figure 3.1 Responder Safety 14

List of Tables

Table 3.1 Station 33 – HAZMAT Focus Group for Needs Assessment...................................... 13

List of Abbreviations (optional)

Mid-America Transportation Center (MATC)
Nebraska Transportation Center (NTC)
Personal protective equipment (PPE)
Internet of things (IoT)
Real-Time Emergency Communication System for HAZMAT (REaCH)
Hazardous materials (HAZMAT)
Pipeline and Hazardous Materials Safety Administration (PHMSA)
Office of Hazardous Materials Safety (OHMS)
National Fire Protection Association (NFPA)
First responder (FR)
Omaha Fire Department (OFD)

Disclaimer

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Abstract

The goal of this project is to develop an information technology system to help minimize the impact to first responders' health during a transportation related HAZMAT incident. We will develop a dashboard prototype that integrates health and environmental data that is collected and transmitted using IoT sensors. This data will allow the Incident Commander and Safety Officer make strategic decisions to protect first responders and transportation workers. The prototype system is called REaCH – **R**eal-Time **E**mergency **C**ommunication System for **H**AZMAT Incidents. REaCH will include real-time health monitoring of first responders and transportation workers through wearable devices that monitor exposure to hazardous materials. A user interface that presents a dashboard prototype with the integrated sensor data is the planned outcome. This is a multi-year project. This report presents the activities in the first year.

Chapter 1 Introduction

1.1 Organization of the Report

In this document we report on the first-year activities for the REaCH - Real-Time Emergency Communication System for HAZMAT Incidents project. This report begins with background on the HAZMAT transportation domain in the context of this project. Next, we describe the goal of our project. Subsequently, we report on the activities and research conducted to date including 1) interviews with Nebraska transportation professionals, first responders, and key stakeholders, 2) focus group findings, 3) a review of current biosensor and wearable technologies, 4) requirements for an integrated sensor dashboard design, 5) a survey that will be distributed and analyzed in year 2, and 6) other notable activities.

1.2 Background

According to the U.S. DOT Pipeline and Hazardous Materials Safety Administration (PHMSA), Office of Hazardous Materials Safety (OHMS), hazardous materials traffic in the U.S. now exceeds 800,000 shipments per day (Lasisi, 2012) and results in more than 3.1 billion tons of hazardous materials annually (The Office of Hazardous Materials Safety Research and Special Programs Administration). Approximately 300 million shipments of hazardous materials are transported annually within the United States. Out of these, 94% of the HAZMAT shipments are moved by trucks (Lasisi, 2012). Between 2007 and 2016, there were 144,002 HAZMAT incidents on US highways, with damage totaling nearly $600M (Office of the Federal Register National Archives and Records Administration, 2011). The top two incident types in the past three years involved flammable-combustible liquids and corrosive materials.

The sensitivity and risks of HAZMAT shipment transportation requires a collaborative framework with technology that enables reliable and cost-effective means to communicate and exchange data during incidents. Today, individual companies track and monitor the status of their trucks and drivers using a range of Intelligent Transportation Systems in the Internet of Vehicles.

Transporting hazardous materials safely, establishing requirements for real-time emergency response information, and monitoring human exposure from hazardous material incidents are national concerns. These concerns are documented in the Fixing America's Surface Transportation Act, or "FAST Act." President Obama signed into law on December 4, 2015.

Past research reports that transportation companies lack real-time monitoring of their drivers transporting hazardous materials. In some cases, the status of hazardous materials is not being measured, and thus potential risks are difficult to identify and are not reported in a timely manner to drivers. Should a hazardous material incident occur the condition of the drivers' and first responders' exposure needs to be monitored closely. This could be made possible via wearable devices that have sensory technology.

A recent study reported that it was difficult for an "Emergency Response Coordination Center" to obtain basic information (e.g., name, nature, and quality of the hazardous materials, etc.) and real-time information (e.g., the location of an accident, the severity level of an accident, etc.) of vehicles, drivers and hazardous materials during the transportation (Ma et. al, 2014). In the first year of our study we conducted focus groups to further assess the current situation in Nebraska.

During such HAZMAT emergencies, first responders are the first to reach the incident site. A first responder is an individual who would immediately be present at the scene during a HAZMAT emergency. They include the fire department, police department, emergency medical services and the department of environmental quality. Over the last few years, there has been an increase in the number of deaths of the first responders caused mainly due to cardiac arrest, heat stroke, stress, lack of oxygen in the blood, and inhalation of hazardous chemicals. National Fire Protection Association (NFPA) statistics reveals the following (National Fire Protection Association, 2017):

- There were more than 30,000 firefighter injuries between 2010-2016
- 42% of fatalities were caused due to physical stress and overexertion
- First responders face a 14 percent increase in cancer-related deaths

1.3 Project Goal

The main goal of our project is to design, develop, and test a technology prototype that will minimize the health impact of first responders when responding to a transportation related HAZMAT incident. Specifically, we plan to create a real-time human and environmental integrated dashboard information system for HAZMAT incident monitoring that could potentially be used in Nebraska and the U.S. The development of the technology prototype follows the agile information system development methodology. For the first phase of our project, we conducted several requirements gathering activities including a literature review, interviews with key stakeholders, focus group with first responders, a review of current sensor technology and prepared a research study on best practices for human health parameters visualizations of data on the dashboard.

This research project intends to address several issues related to the health of transportation workers and the first responders in the presence of hazardous materials. Our goal is to provide real-time information to decision makers and incident commanders during a HAZMAT incident. Currently, the ability to identify and communicate information on various human health parameters on an integrated user interface platform is limited. Our aim is to develop a prototype that includes wearable sensor devices, mobile apps, and a real-time communication network all first responders and transporters can use during a hazardous materials incident. The new system is called REaCH - Real-Time Emergency Communication System for HAZMAT Incidents. The activities for year 1 were:

- Defining the REaCH system requirements. (See Appendix A)
- Interviewing HAZMAT carriers, NE Transportation stakeholders, various units of first responders at Omaha Fire Department
- Conducting a focus group workshop with HAZMAT first responders.
- Meeting with local hazardous material response teams to identify health monitoring and exposure data needed over a multi-year period for multiple response scenarios.
- A broad review of the current state of wearables for HAZMAT protection, current IoV technology, Intelligent Transportation Systems, and current technology used in the field. Two project team members attend the International HAZMAT and Firefighters conference to learn about the latest technology in the field.
- IRB approval to conduct interviews, focus group workshop with stakeholders and to survey OFD firefighters on their use and attitudes toward health monitoring wearables.

Chapter 2 Literature Review

2.1 Sensor Technologies

In our project we intend to leverage Internet of Things (IoT) technologies that support human and environmental data capture and transmission through sensors. There are many wearable IoT sensor technologies available that could be utilized in our project. We conducted a broad review of the current state of the technology. Below we present our findings.

2.1.1 Wearable Technology/Wearable Devices

Wearable Technology/Wearable Devices refer to all electronic technologies that can be incorporated into clothing, accessories or computing devices that can be comfortably worn on the body. A special feature of wearable devices is that they can provide real time information to their users and those monitor the users' health.

With the latest developments in technology, the Internet of Things (IoT) has paved the way for monitoring healthcare through the evolution of wearable devices built using wearable sensors. The increasing need for self-health monitoring and preventive medicine had given rise to the development of numerous wearable devices, which can be used to monitor health parameters such as body core temperature, heart rate, blood pressure, blood oxygen level, hydration level etc. in various areas. Wearable systems range from microsensors integrated efficiently and effectively into textile materials such as exoskeleton, computerized watches, earplugs, hand gloves, and bracelets to computerized eye glasses such as the Google glass.

Personal Protection Equipment (PPE) are specialized clothing designed for first responders. PPE provides protection from serious injuries and illnesses resulting from contact with chemical, radiological, physical, electrical, and other hazards. Wearing PPE often puts a first responder at considerable risk of developing heat stress. This can result in health effects ranging from heat fatigue to serious illness such as heat stroke and cardiac failure which may cause death. Heat stress is caused by a number of interacting factors, including environmental conditions, clothing, workload, and the individual characteristics of the worker.

First responders are often subjected to working in extreme environmental conditions. The Personal Protection Equipment, Self-Contained Breathing Apparatus and the remaining set of safety gear acts as an extra load on their body especially under strenuous conditions where the temperature can be extremely dry or extremely wet. One of the main challenges of PPE is the inability to eliminate heat through radiation, convection (transfer of heat through mass motion) and evaporation. The PPE is impermeable in nature which is good from a chemical resistant point of view, but it also prevents the elimination of heat, which results in the lack of heat loss in PPE.

The first responder wearing the PPE will produce his or her own body heat in addition to the temperature conditions outside the PPE. The suit also impedes the wearer's ability to balance the heat production and heat dissipation. This results in the degradation of the effectiveness of the individual i.e. as their core body temperature increases ($TC>37°C$), their cardiac output i.e. their heart rate increases.

Temperature and humidity affect the thermal balance of the human body via skin and the respiratory system. So, if there is no scope of evaporation inside the PPE, then the heat dissipated from the first responders' body will have a no way out, thus resulting in the dryness of skin and other harmful conditions which may be fatal. Thus, it is extremely important to monitor the temperature and humidity inside and outside the protection suit of the first responder when subjected to strenuous conditions. Monitoring these parameters can be achieved through biosensors – which are unobtrusive, durable, can be easily worn, and which can be used as an intervention during crisis emergency response.

The following section gives an overview of the different health monitoring sensors and their functionalities.

2.1.2 Health Monitoring Sensors

2.1.2.1 Telemetry pill

The telemetry pill is able to measure the core temperature directly because the sensor travels through the Alimentary Canal (Byrne et al., 2006). The size of the telemetry pill is similar to a regular pill capsule. Radio frequencies are emitted by the sensor and sent to an external device that records the signals and displays the core temperature data to the user. The pill itself consists of a temperature sensor, radio transmitter, battery and onboard memory. Memory in the pill is to store temperature values at various intervals. Disadvantages are single time use and it is relatively expensive.

2.1.2.2 Zero – Heat Flux sensor

The zero heat-flux sensors are non-invasive and are placed on the forehead. The zero heat-flux sensor bases its core temperature measurement off the bio heat equations for the head's tissues layers and Fourier's heat equation for the foam layer. The device calculates the core temperature through an iterative warming process of the heating element.

An example is the 3M SpotOn Temperature Monitoring System (SpotOn). It is reported as being an accurate, non-invasive system that measures patients' temperatures with an affordable single-use sensor, and provides consistent temperature monitoring.

2.1.2.3 AliveCor's Kardiaband

The AliveCor's Kardiband is a heart rate monitoring system (KardiaMobile). Kardiaband can capture a medical electrocardiogram in 30 seconds anywhere and anytime. It is used by the world's leading cardiac care medical professionals and patients. It has a battery with an operational time of 200 hours and it is compatible with android and IOS platforms.

2.1.2.4 LilyPad Temperature Sensor

The LilyPad detects temperature changes. The MCP9700 is a small thermistor type temperature sensor. This sensor can output 0.5V at 0 degrees C, 0.75V at 25 C, and 10mV per degree C. The LilyPad converts analog to digital that allows the user to establish the local ambient temperature. It can detect physical touch based on body heat and ambient conditions using a small sensor. The LilyPad is a wearable e-textile technology developed by Leah Buechley and cooperatively designed by Leah and SparkFun. Each LilyPad was creatively designed to have large connecting pads to allow them to be sewn into clothing. Various input, output, power, and sensor boards are available. They are even washable.

2.1.2.5 Hot Dot Alert Patch by OSHA

The Hot Dot Alert Patch is a single-use indicator that can help ALERT users of the potential risk of heat-related illness and potentially prevent heat-related injuries and save lives. The Hot Dot Alert Patch used thermo chromatic (property of a substance to change color due to the changes in temperature) technology. The Hot Dot Alert Patch offers real-time monitor of body temperature changes.

2.1.2.6 Zephyr

The Zephyr H x M BT is the first fitness-tracking device that supports both Android and Windows Phone 8 devices. It combines smart fabric, heart rate sensor technology, movement sensors, and Bluetooth connectivity on a chest strap. It is used to extract heart rate information from patients who need continuous monitoring. Due to its Bluetooth low energy technology, it makes the device highly durable, reliable, accurate and comfortable.

Zephyr consists of machine washable straps, a compression shirt and flame resistant wearable shirts. Zephyr's physiological monitoring module helps capture and transmit physiological data on the wearer via mobile and data networks. It is used to capture ECG, respiration, core body temperature, acceleration, time and location of the wearer.

2.1.2.7 Drager – TCORE

The Drager – TCORE is a non-invasive temperature monitoring system. It employs a dual-sensor heat flux technology, which monitors and calculates the core body temperature accurately and continuously. It requires a simple self-adhesive sensor to be placed on the wearer's head.

2.1.2.8 Polar OH1

The Polar OH1 is an optical heart rate sensor (Polar OH1). This heart rate monitor armband can accurately and consistently capture heart rate using Polar's heart rate algorithm and 6-LED solution. It is Bluetooth enabled and is easily compatible with IOS and Android with a battery life of 12 hours.

2.1.2.9 Pulse sensor

The Pulse sensor is used to test the heart rate of the user through an Arduino connection. It displays the user's real time heart rate information through an open source app. The Pulse sensor is a simple optical sensor that works by taking advantage of changes in light scattering as a result of increased blood flow. As the heart beats, the volume of blood in the arteries and veins increases rapidly.

2.1.2.10 Texas Instruments CC2650 Sensortag

The Texas Instruments CC2650 Sensortag is an ultra-low power Bluetooth sensor tag which supports the following sensors: temperature, pressure, humidity, accelerometer, gyroscope and magnetometer. The device comes with a TI sensortag app available on both IOS and android where the data can be captured in a real time environment and can be stored and visualized on the IBM cloud platform through Internet of Things (IoT) technology.

2.1.2.11 CHASE LifeTech FR

The CHASE LifeTech FR (Nokia)] is a Nokia produced product in collaboration with Kolon, a fashion brand in Korea. The jacket is composed of module sensors, which allows the wearer to access data such as heart rate, body temperature, location and motion. The data is captured in a real time environment and can be visualized using GINA's software management system. This product was designed to increase the safety of the first responders and mitigate risks associated during an emergency response.

Chapter 3 Research Approach and Methods

The team employed several research approaches and methods, including requirements gathering and data analysis to understand the needs of the stakeholders in the HAZMAT response field. We conducted interviews and a focus group workshop, and surveyed biosensor, HAZMAT, and first responder health concerns literature. We met with subject matter experts (SMES) in Omaha and around the world at the International HAZMAT and Firefighters conference.

Our project began with defining the REaCH system requirements. Our goal is to move from conceptual technology ideas and visions to building, testing and evaluating working prototypes in the field with end users. We are following best practices in an iterative development approach known as Agile Development. A flowchart of the Agile Development approach is shown in Appendix A.

We are employing the IT Industry Standards Unified Modeling Techniques (Booch et al., 1998) as part of our analysis efforts. For example, we utilized use case diagrams and user scenarios as our modeling tools. A sample use case diagram and examples of user scenarios are shown in Appendix B.

3.1 Focus Groups

3.1.1 Omaha Fire Department Special Operations

UNMC Institutional Review Board (IRB) approval was obtained to conduct a systematic process for data collection in a focus group format. Participants were recruited from Omaha Fire Department Station 33 HAZMAT team members with the goal to elicit a consensus on their perceptions of the hazards they encounter and their personal and health concerns due to HAZMAT incidents responses, to better delineate the outcome products for this project. The following represents the procedures for the focus group data collection and the results that were generated. After introductions. Dr. Fruhling, PI, provided an overview of the project. Dr. Medcalf then facilitated the session. First, the participants were given a half sheet of paper and asked to list items in response to the following question: When you are responding to a HAZMAT event, what are the things that you worry about? The participants were asked to list at least ten items. Then each item was transferred to its own post-it note and participants were asked to place their top 4-5 items on the table. Following questions of clarity on the items on the table, participants were asked to group the notes that were similar. This process was repeated until all notes were on the table and clustered into groups. Participants were then asked to assign a name or theme to each cluster.

The cluster with the most notes (items) was chosen and each note was placed in a row at the top of the table. Participants were asked to begin to create additional post–it notes that represented "solutions" to any or all the notes (items) on the table. Participants were instructed to think of solutions that were not limited by time, technology or availability of funding. Solution post-it notes were placed in a column below each original item that derived from the cluster that generated the most concerns.

Table 3.1 below represents the clusters of items that participants considered concerns when they respond to a HAZMAT event. Thematic areas include: Responder Safety; Training; Risk Assessment; Incident Command; Personal Protective Equipment; Weather and Location; Communication; Hazard/Product Identification; Public Safety and Post Incident Review. Each item under "Concerns" represents an individual note placed by all participants.

Table 3.1 Station 33 – HAZMAT Focus Group for Needs Assessment

Themes	Concerns	Notes
Responder Safety	Safety of responders	Life safety
	Fire fighter accountability	Respondent exposure
	Potential external hazards	Long-term health effects
	Adequate staffing?	Education/awareness of political level
	Exit strategy if things go bad	Taking home to family Incident stabilization/ property conservation
Training	Sufficient training	Previous incident experience
	Proper equipment/tools	
Risk Assessment	Secondary explosions	Bioterrorism
Incident Command	Subject matter expert available?	Will proper procedures be followed by incident commander?
PPE	Adequate PPE/ Proper/correct PPE	Extra resources
	Can't see	Maintenance and equipment
Weather and Location	Exact location of spill/leak; topography	Weather conditions
Communication	Communication to the community	Communication before we get to the scene
	Communication among responders (own unit) and interagency	Information collection and dissemination
Hazard/Product Identification	Stop problem/mitigation/stabilization/isolation	How big is the spill/leak
	Equipment needed for ID/Mitigation	Accurately identify hazard/product
	Accurate information	Mixed products
	Building layout/incident layout	Data gathering
	Equipment working?	How/what will HAZMAT change?
Public Safety	Evacuate vs shelter	Where can HAZMAT go?
	Property conservation	Notify and evacuate potential victims
	How many have been exposed/potential victims?	Safety of citizens/public
Post Incident Review	Interagency results and findings	Lessons learned
	What to do differently next time	What worked/what didn't

The diagram below (Figure. 3.1) represents the brainstormed solutions to the items of concern clustered under the thematic area entitled: Responder Safety. White boxes indicate the original concerns from the notes generated by participants. The blue boxes represent the solutions that participants wrote for any or all of the concerns.

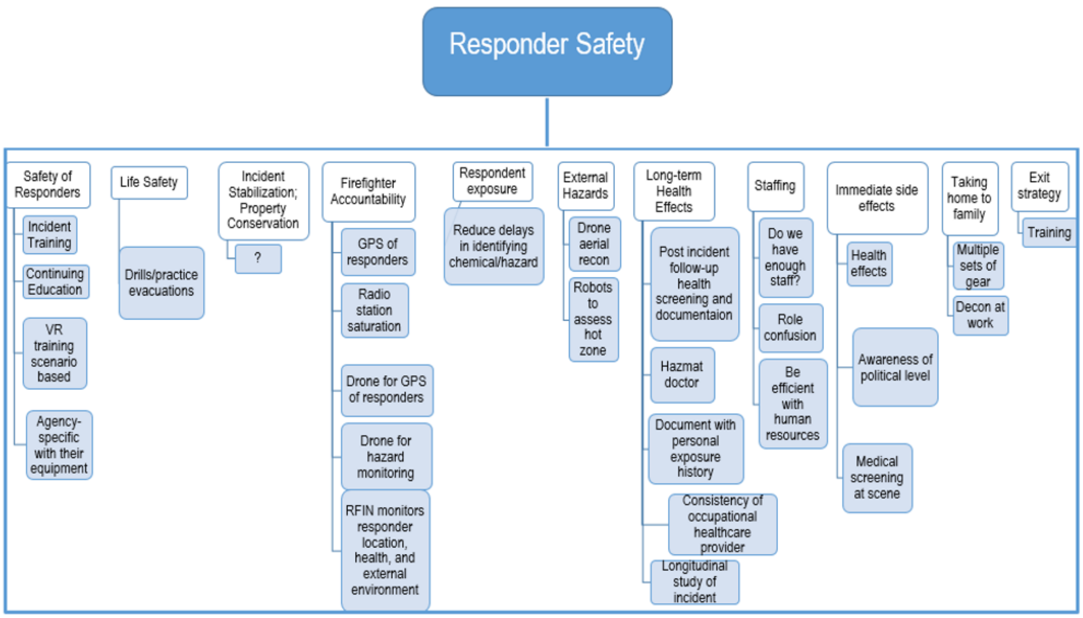

Figure 3.1 Responder Safety Themes and Concerns

3.1.2 HAZMAT Haulers Interviews

In June 2018, Drs. Ann Fruhling and Chandran Achutan met with the CEO of a trucking company in Omaha. The purpose of the meeting was to understand the health and safety concerns of the trucking industry. The company employs between 130 and 140 truckers. They work 14 hours a day; they drive up to 11 hours a day. They are allowed to work 70 hours over 8 days before they have to take 34 hours of rest. This company transports gases such as nitrogen, oxygen, argon, carbon dioxide, hydrogen, helium, hydrogen chloride, ethylene, and carbon monoxide. Potential health and safety hazards include asphyxiation in confined spaces. When the truckers are in refineries, truckers wear oxygen and hydrogen sulfide monitors. Trailers are not washed—they do not change chemicals. They are purged. Sometimes there are fuel spills and oil leaks; truckers usually have PPE on hand. The trucks have satellite devices which monitor speed, truck performance, and sudden stops and starts. Cameras that face inwards and outwards capture driver behavior.

CEO raised the following health and safety concerns:

- Unknown chemicals at the destination
- Physical security of truckers from guns
- Counter terrorism threat as trucks cross across Country land borders
- Lack of place to park the trailer at night.

The CEO offered to allow truckers to participate in a focus group with our research team.

Dr. Chandran Achutan also participates at the monthly Safety Meetings at the Omaha Fire Department (OFD). He is a Certified Industrial Hygienist and advises OFD on workplace health and safety policies.

The project team met with Lincoln-Lancaster County Health Department, Ron Eriksen, the faculty in the UNO Emergency Management program, faculty in the Biomechanics program that have expertise in health biosensor research. The team also had numerous interviews with Omaha Fire Department leadership, fire fighters and special operations unit members.

3.2 Integrated Sensor Dashboard Design

A first responder (FR) is an individual who arrives first at a hazardous material incident site and takes the initiative to act in order to minimize the risk to public health and property. Often the FRs are firefighters. Information collected interviews and focus groups above revealed that the FRs may experience severe health related issues due to physical exertion, psychological stress and extreme working conditions. These issues range from thermoregulatory exhaustion and acute dehydration to fatal cardiac arrest, cancer and suicides. Research shows that 39% of FR fatalities are due to heart failure and 61% due to reasons like trauma, burns, etc. (Perroni et al.,2014).

To ensure FRs' safety, the incident commander (IC) monitors critical information about FRs and the incident site. The IC's decision regarding FRs' safe evacuation or withdrawal from the site is dependent on the collected information. The most critical parameters for an IC to monitor during such emergencies are FR's heart rate, core body temperature, available oxygen percentage and environmental air quality.

As part of our goal of this project to develop a Dashboard prototype, a smaller study conducted by a graduate student will focus on most usable display formats to visualize FR critical health and environmental data. In this study, each identified critical parameter will be represented through different design display formats. The designs will be developed iteratively using standard guidelines and feedback from expert UI designers. These designs will be examined in a scenario-based simulated testing environment. The study will follow a mixed-method approach involving a qualitative open-ended responses and survey data to evaluate the usability of these designs. In the first year of this project, the study was designed and IRB approval was completed.

3.3 First Responders' Wearable Technology Survey

The First Responders' Wearable Technology Survey was developed in the College of Public Health at the University of Nebraska Medical Center on behalf of the Real-Time Emergency Communication System for HAZMAT Incidents (REaCH) project. The survey is designed to gain more insight into first-responders' use of technology and identify methods that further our understanding of monitoring exposure to hazardous environments.

This information will not only help identify the feasibility of first responders using wearable technology for monitoring real-time diagnostics during environmental incidents, but it will also help determine the viability of using wearable technology for monitoring first responders' health when responding to an incident.

All the information provided will be kept confidential and personal identifying information (email, etc.) will be separated from responses to ensure that no individual can be identified. If first responders would like to be contacted for a follow-up interviews, they voluntarily provide their email address following the completion of the survey. Participation in this survey is voluntary but their participation is critical to help understand first-responder incidents and to develop methods that will prevent workplace injuries.

In the second year, the First Responders' Wearable Technology Survey will first be sent to a Special Operations Unit of the Omaha Fire Department (n=20). In the second phase of distribution, the survey will be sent to the entire Omaha Fire Department (n=500).

3.4 Other Notable Activities

Two graduate students presented there literature research and research project at the annual UNO Student Research Fair. The posters are presented in Appendix D and Appendix E. Vikas Sahu 's poster presentation, "Visualize to Realize: Improving Safety of First Responders." Received the Meritorious Graduate Poster/Demonstration (third place) Award out of 150 student poster presentations. <https://digitalcommons.unomaha.edu/srcaf/2018/schedule/177/>. Graduate student, Chaitra Venkatesan also had a poster presentation called "Testing Environmental Sensors to Reduce Health Ailments among First Responders." Drs. Sharon Medcalf, Aaron

Yoder, Chandran Achutan, Matt Hale and Ann Fruhling presented the focus group needs Assessment results to the Engine 33 Special Operations Unit part of Omaha Fire Department.

Graduate Student Vikas Sahu and Dr. Ann Fruhling presented and published a paper in the proceedings of the Americas Conference for Information Systems. (Sahu & Fruhling, 2018a), (Sahu, 2018b). Graduate student Chaitra Venkatesan, Dr. Sharon Medcalf and Dr. Ann Fruhling presented and published a paper in the proceedings of the Americas Conference for Information Systems (Venkatesan et al., 2018a), (Venkatesan et al., 2018b).

As a direct result of the partnership developed between our research team and the Omaha Fire Department, we submitted a research grant related to firefighters, to the Department of Homeland Security (Achutan, PI; Fruhling, Co-PI). The title of the grant was, "Preventing heat-related illnesses in firefighters through integrated sensors." The grant had the following specific aims: 1) Assess participants' work practices, work equipment, and comfort with technology. 2) Design a novel, user-friendly way to integrate temperature, relative humidity, and heart rate sensors in firefighter suits. 3) Evaluate the efficacy of the integrated technology in Personal Protective Equipment (PPE) to mitigate heat-related illnesses. The grant was not funded, but we plan to submit a modified version to the National Institute for Occupational Safety and Health.

Chapter 4 Future Work

In year 2, the project team will continue developing, building the prototype REaCH – **R**eal-Time **E**mergency **C**ommunication System for **H**AZMAT Incidents prototype. We will survey OFD first responders and local long-distance haulers attitudes towards, behavior and usage of wearable health sensor devices. We will partner with biomechanics scientists who can assist in validating the health data from the sensors. We will beta testing our integrated health and environmental sensor dashboard.

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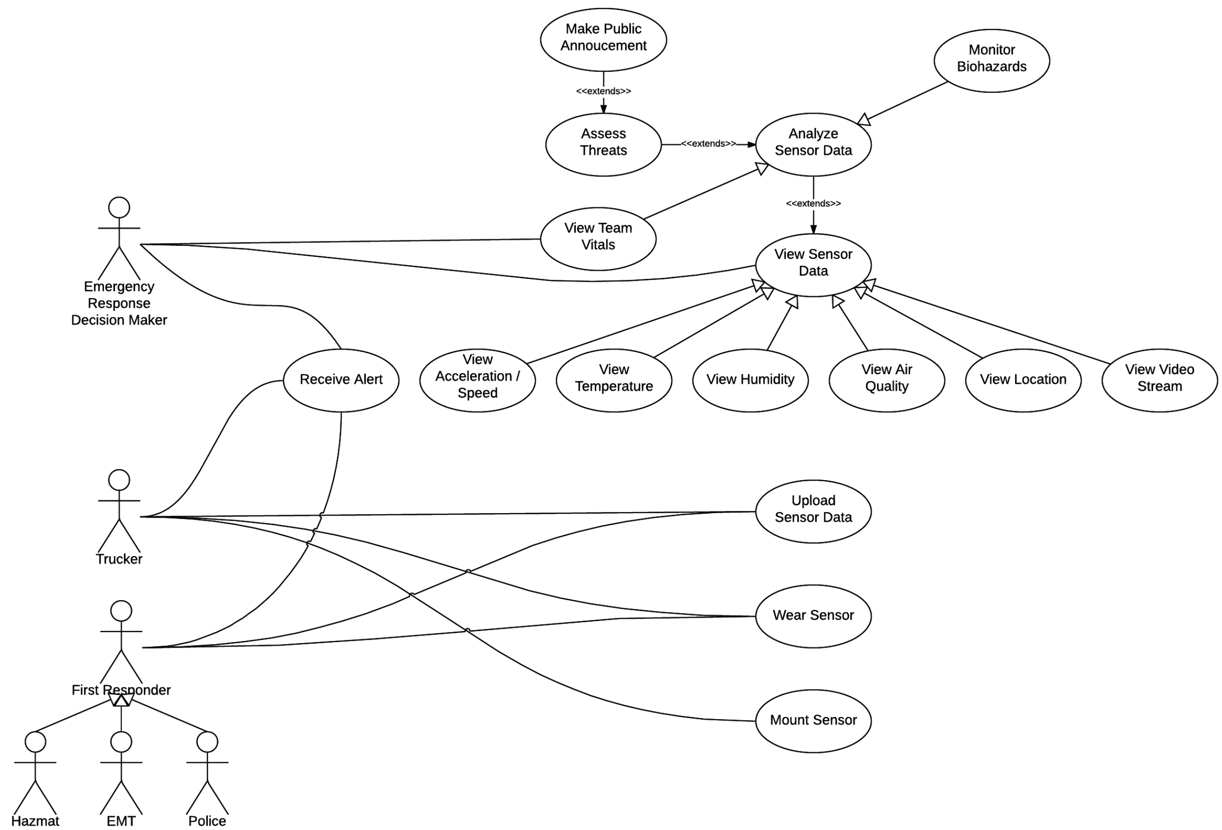
Appendix A Sample use case diagram and user scenarios.



Backlog

1. As a researcher, I must know when the device is powered on and off, so that I know that I can record my participant's data.
2. As a researcher, I need to know that the dashboard is displaying sensor data, so I know that device is transmitting data and the dashboard is receiving data
3. As a researcher, I need to be notified about a transmission error with the sensor, so I know that I can troubleshoot (this needs to be further defined)

4. As a HAZMAT captain, I want to read data from smart devices, so that I can more accurately identify hazards.
5. As a HAZMAT captain, I want to read data from smart devices, so that I can more rapidly identify hazards.
6. As a HAZMAT tech, I want to monitor the health of individuals on my team, so that I can extricate them from dangerous situations.
7. As a HAZMAT tech, I want to keep track of my team, so that I can strategically deploy resources.
8. As a HAZMAT captain, I want to communicate with corporate entities, so that I can more rapidly identify hazards.
9. As a HAZMAT first responder, I want to receive alerts if my vitals are at abnormal levels, so that I can avoid the area to maintain my health and safety.
10. As a HAZMAT first responder, I want to be able to identify hazards quickly, so that I can better adapt to and mitigate the situation.
11. As a researcher, I want to be able to jump to a particular date/time in the dataset, so I quickly go to a particular section of data.
12. As a researcher, I want to be able to customize the dashboard, so I can select, view and organize specific datasets.
13. As a researcher, I want to be able to be able to see the information in movable panes, so that I can focus on just the information I want.
14. As a designer/researcher, I want the information to be color blind accessible, so that a wider range of people are able to effectively use the interface.

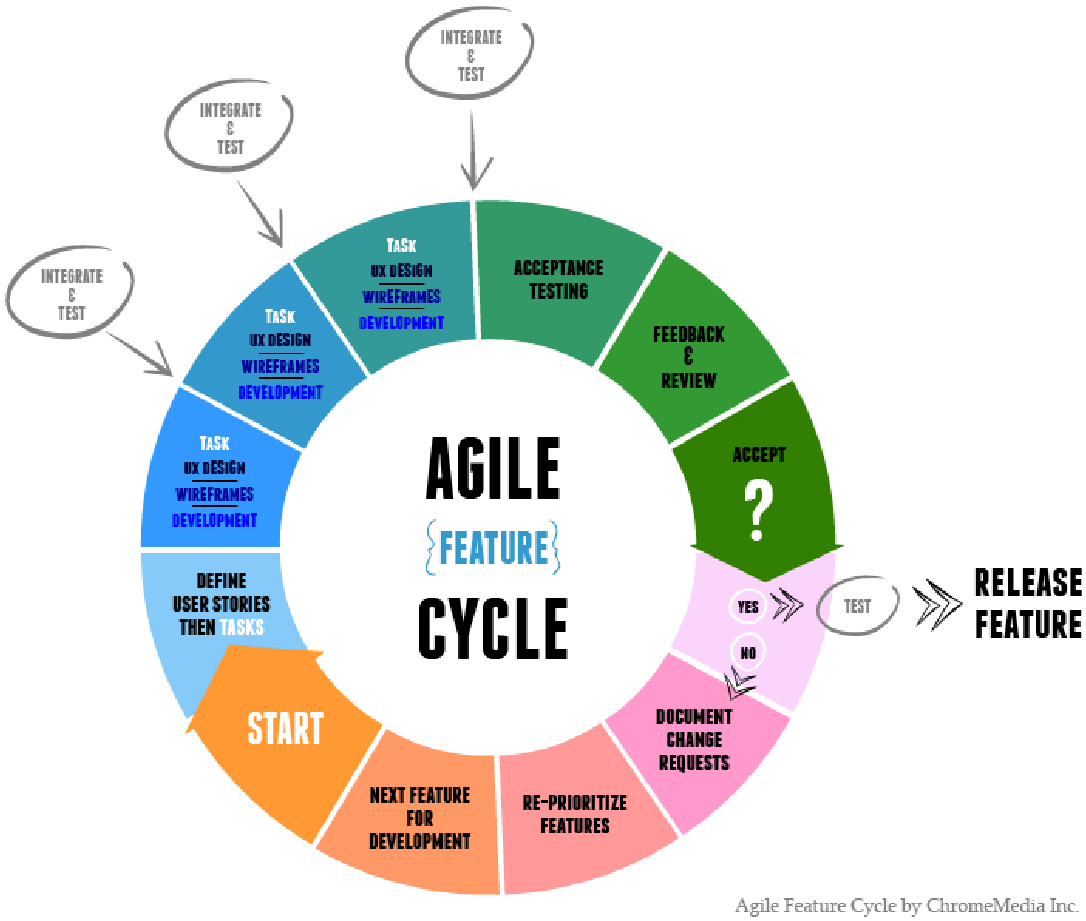
15. As a researcher, I want to see data organized by participant, group, or other attributes, so that I can compare the data and do analysis.
16. As a researcher I need to login to the dashboard so that the data is protected.
17. As a researcher I need to be select which function I want to do (e.g. view data, connect sensors, etc.)
18. As a researcher I need to be able select the sensor(s) I want to connect for transmission so that data is being captured.
19. As a sensor I need to have day and time included in the data that is transmitted so that the researcher can group the data and a particular participant can be identified.
20. As a researcher I need to be able to assign a sensor to a participant so that I have association of a participant.
21. As a researcher I need be able to add an event as a marker on the current data so I can go back and do further analysis.
22. As a researcher I need to have the EPCOH data to be converted to the local timezone since it is collect in GMT time so that the time and data matches the local time zone.
23. As a HAZMAT first responder, I want to read data from smart devices, so that I can more accurately identify hazards.
24. As a HAZMAT captain, I want to keep track of my team, so that I can strategically deploy resources.
25. As a HAZMAT captain, I want to keep track of my team, so that I can help them avoid hazards.
26. As a HAZMAT captain, I want to monitor the health of individuals of on my team, so that I can track longitudinal health and safety.

27. As a HAZMAT first responder, I want to be able to identify hazards accurately, so that I can better adapt to and mitigate the situation.
28. As a HAZMAT captain, I want to monitor the health of individuals on my team, so that I can extricate them from dangerous situations.
29. As a HAZMAT captain, I want to identify hazards quickly, so that I can strategically deploy and initiate the correct resources to mitigate them.
30. As a HAZMAT first responder, I want to read data from smart devices, so that I can more rapidly identify hazards.
31. As a HAZMAT captain, I want to keep track of my team, so that I can help them if they are in distress.
32. As a HAZMAT first responder, I want to keep track of my teammates, so that I can help them if they are in distress.
33. As an admin, I want to be able to assign a sensor to a user during the setup process, so that I know where their data is coming from.

In Progress

34. As a HAZMAT tech, I want to keep track of my team, so that I can help them avoid hazards.
35. As a HAZMAT tech, I want to keep track of my team, so that I can help them if they are in distress.

Appendix B Agile methods flowchart.



Agile development utilizes a *feature* centric approach that guides the definition and realization of *user stories*. User stories are, as the name implies, short descriptions of the kinds of activities a user is involved in relation to the software. User stories are structured and define the type of *user involved*, the *action* they want to take, and the *goal(s)* of the action as they relate to the user. This structure forms the basis of a software requirement that is implemented as a feature. Feature development is not monolithic, so as user stories are defined, their realization (or achievement) is decomposed into a set of synchronous or asynchronous tasks. Once the tasks are completed, they produce code artifacts that are then integrated together, tested, reviewed, and either accepted or not. If a feature is accepted, then development proceeds onward to the next user story. If not, new tasks are created to realize the story, the story is changed given lessons learned, or the development team re-focuses on other important features needed for the final product. Ultimately, when the core user stories related to a feature are realized, the feature can be released. Often feature releases are grouped together into a new overall product version.

Appendix C Survey

First Responders' Wearable Technology Survey

1

IRB Protocol # 691-17-EX

July 18, 2018

Dear First Responder,

The following survey is being conducted by the College of Public Health at the University of Nebraska Medical Center on behalf of the Real-Time Emergency Communication System for HazMat Incidents (REaCH) project, which is supported by USDOT UTC Grant #69A3551747107. With your help, we hope to gain more insight into first-responders use of technology and identify methods that further our understanding of monitoring exposure to hazardous environments.

This information will not only help up us identify the feasibility of first responders using wearable technology for monitoring real-time diagnostics during environmental incidents, but it will also help determine the viability of using wearable technology for monitoring your health when responding to an incident.

It should take less than 10 minutes to complete the following survey. All the information you provide will be kept confidential and your personal identifying information (email, etc.) will not be connected to your responses to ensure that no individual can be identified. Participation in this survey is voluntary, however your participation is critical to help us understand first-responder incidents and to develop methods that will prevent workplace injuries. You may stop participating at any time, and your responses will be deleted. If you have any questions about the survey, please email or call me at the number listed below.

Thank you for your time and consideration.

Sincerely,

Aaron M. Yoder, PhD
Assistant Professor
University of Nebraska Medical Center
Environmental, Agricultural and Occupational Health
402.552.7240
aaron.yoder@unmc.edu

2

Are you part of Special Operations?

- Yes
- No

3

What year were you born? (YYYY)

Please enter a number less than or equal to 2000

4

Have you ever used wearable technology (Fitbit, Smart Watch, etc.)?

- Yes
- No

5

Do you currently use wearable technology?

- Yes
- No

6

Why don't you use wearable technology?

Enter your answer

7

How confident are you in your ability to operate wearable technology?

- ◯ Extremely confident
- ◯ Very confident
- ◯ Somewhat confident
- ◯ Not so confident
- ◯ Not at all confident

8

If someone were to monitor your HEALTH while working in the field, who would you prefer?

- ◯ Myself
- ◯ My SIMS Operator
- ◯ My SIMS Operator and myself
- ◯ Neither, I prefer not to have my health monitored
- ◯ Other

9

In your opinion, what types of HEALTH information would be useful to monitor for first responder safety when working in the field.

	Yes	No	Don't Know
Heart Rate	◯	◯	◯
Blood Pressure	◯	◯	◯
Core Body Temperature	◯	◯	◯
Skin Temperature	◯	◯	◯
Hydration Level	◯	◯	◯

10

In your opinion, what types of HEALTH information would be useful to monitor for first responder safety when working in the field.

	Yes	No	Don't Know
Stability	○	○	○
Falls	○	○	○
Breathing Rate	○	○	○
Breathing Depth	○	○	○
Blood Oxygen Levels	○	○	○
Respiration CO2 Levels	○	○	○
Cortisol Levels (Stress)	○	○	○
Skin Resistance (Stress and Hydration)	○	○	○

11

In your opinion, are there any additional types of HEALTH information that would be useful to monitor for first responder safety. If so, please list below.

Enter your answer

12

If someone were to monitor your ENVIRONMENT while working in the field, who would you prefer?

- ○ Myself
- ○ My SIMS Operator
- ○ My SIMS Operator and myself
- ○ Neither, I prefer not to have my environment monitored
- ○ Other

13

In your opinion, what types of ENVIRONMENTAL information would be useful to monitor for first responder safety.

	Yes	No	Don't Know
PH			
Oxygen			
Carbon Monoxide			
Hydrogen Sulfide			
Combustible Gases			
Ammonia			
Particulates			
Carbon Dioxide			
Biological Proteins			
Radiation			

14

In your opinion, what types of ENVIRONMENTAL information would be useful to monitor for first responder safety.

	Yes	No	Don't Know
LEL - Lower Explosive Limit			
Temp (inside suit)			
Temp (outside suit)			
Humidity (inside suit)			
Humidity (outside suit)			
Noise - Sound Level (inside suit)			
Noise - Sound Level (outside suit)			
Hydrogen Cyanide			
VOCs - Volatile Organic Compounds			
PHCs - Polyhalogenated Compounds			

15

In your opinion, are there any additional types of ENVIRONMENTAL i
be useful to monitor for first responder safety. If so, please list below

Enter your answer

16

Questions, Comments, and/or Concerns?

Enter your answer

Appendix D Testing Environmental Sensors to Reduce Heat Ailments among First Responders

UNIVERSITY OF NEBRASKA AT OMAHA

Testing Environmental Sensors to Reduce Heat Ailments among First Responders

Chaitra Venkatesan, Matt L. Hale, PhD, Ann L. Fruhling, PhD

Introduction

Over the last few years, there has been an increase in the number of deaths of the hazmat first responders mainly due to cardiac arrest, heat stroke, heat stress, lack of oxygen in the blood and inhalation of hazardous chemicals. National Fire Protection Agency (NFPA) statistics reveal the following:

- There were more than 30,000 firefighter injuries between 2010-2016.
- 42% of fatalities were caused due to physical stress and overexertion.
- The hazmat first responders face a 14 percent increase in cancer-related deaths (NIOSH).

Past research and interviews with various focus groups have indicated that there is a lack of real time health monitoring for first responders during a hazmat response. It is extremely important to monitor the health and environmental parameters surrounding the hazmat first responders in order to improve their safety and mitigate their deaths.

A decrease or an increase in the core body temperature of a hazmat first responder when exposed to extreme environmental conditions can result in adverse health effects such as heat stroke, cardiac arrest and heat exhaustion. Thus, my primary research goal is to monitor the temperature inside and outside the personal protection suit of first responder in order to improve their health and reduce risks associated when they are subjected to potentially harmful emergency hazmat situation. **This can be achieved through Internet of Things (IoT) sensor technology.**

Background

What is HAZMAT?

Hazardous Material (HazMat) is defined as "a substance or material, including hazardous substance, which has been determined by the Secretary of transportation to be capable of posing an unreasonable risk to health, safety and property when transported in commerce and which has been so designated". [1]

Who are first responders?

A **first responder** is an individual who would immediately be present at the scene during a HAZMAT emergency. They include the fire department, police department, emergency medical services and the department of environmental quality.

What is Personal Protection Equipment (PPE)?

It is a specialized clothing designed for the hazmat first responders to provide protection from serious injuries and illness resulting from contact with chemical, radiological, physical, electrical, and other hazards.

- Wearing a PPE (Personal Protection Equipment) puts a hazmat first responder at considerable risk of developing heat ailments. First responders are often subjected to working in extreme environmental conditions, where the temperature can be severely dry or wet.
- One of the main challenges of PPE is the inability to eliminate heat through radiation, convection and evaporation, where it impedes the wearer's ability to balance the heat production and heat dissipation. [4]
- This can result in degrading the health of the hazmat first responder with harmful conditions ranging from heat fatigue to serious impacts such as heat stroke and death.
- Heat exhaustion is characterized by an increased core body temperature ($T_c > 98$ ° F) and increased heart rate ($BPM > 100$), which can result in causing dizziness, fatigue and low blood pressure in the first responder. If immediate action is not taken to cool the individual, high core body temperature can cause multi-organ dysfunction, which often leads to death.

Temperature and humidity affect the thermal balance of the human body via skin and the respiratory system. Thus, it is extremely important to monitor the temperature and humidity inside and outside the personal protection suit of the hazmat first responder when they are subjected to strenuous environmental conditions.

Research Purpose

The purpose of this research is to:

- Monitor the health parameters of the first responders in an emergency hazmat response through IoT sensors
- Improve their safety and reduce adverse heath effects
- Visualize the IoT sensor data for effective decision making

Acknowledgement

Funding for this research is supported through a US Department of Transportation, University Transportation Center (UTC) Competition 2016 award.

Research Questions

- Can IoT sensor technology be utilized effectively and accurately to monitor first responders' core body temperature during a hazmat response?
- What is the best way to visualize IoT sensor data when monitoring first responders' core body temperature during a hazmat response?
- What is the best way to effectively send alert notifications to the hazmat first responder wearing a PPE when core body temperature is possibly too high?

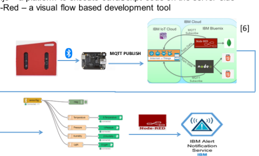
Solutions

- The advancements in Internet of Things (IoT) in relation to wearable sensors has enabled communication between human and things in various areas such as health monitoring, intelligent transportation systems, safety/security, environmental monitoring etc.
- The increasing need for health monitoring and preventive medicine has given rise to the development of numerous wearable devices which can be used to monitor health parameters such as core body temperature, heart rate, blood pressure, blood oxygen and movement. IoT sensors can be incorporated into computed devices to measure these health parameters and can be comfortably worn on the body.
- For our research, we will be using a Texas Instruments CC2650 – an ultra low power Bluetooth sensor tag which has the following sensors: Temperature, Pressure, Humidity, Accelerometer, Gyroscope and Magnetometer.

Technology

All the technological components used for our research are open-source software.

- Texas Instruments CC2650 – a low power Bluetooth low energy sensor tag
- IBM Watson IOT Platform – a cloud hosted service [3]
- IBM Bluemix – to build, manage and deploy applications on cloud
- Node.js – a platform to execute JavaScript code on the server side
- Node-Red – a visual flow based development tool



Integrating Sensor Data on IBM Watson IoT Platform

Functionality

The functionality of the above diagram is described below:

- A low power TI Sensor Tag CC2650 is connected to a mobile device via Bluetooth low energy.
- The device pushes the sensor data onto the IBM Watson Cloud Platform via MQTT protocol.
- The sensor data is obtained is a real time environment and gets updated on the cloud platform every 3 seconds.
- Node.js application connects the TI sensor tag data to the IBM cloud platform.
- Once the data is received on the cloud, a Cloudant database such as dash DB is used to store and fetch the sensor data.
- A Node-Red app is used to analyze and react to the cloud sensor data. Various real time analytics and data visualizations can be performed using the Node-Red application.
- For our research we would be setting a threshold value for the core temperature and humidity; Thus if the threshold is met, additional data can be pulled from the Cloudant database to send alert notifications to the first responder during a hazmat response .

Future Work

- Build a mobile application to visualize sensor data and send alert notifications to the first responder during a hazmat response.
- Test the quality and accuracy of the IoT sensor placed inside the protection suit of the hazmat first responder in a simulated environment.

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University of Nebraska Omaha

Appendix E Visualize to Realize: Improving Safety of First Responders