# Project Proposal: Firefighting Robot

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# 1 INTRODUCTION

Characterized by the rapid rise of digital systems, the twenty-first century is being called an Internet Industrial Revolution. The advancing technologies of this modern industrial revolution are increasing preventability and recovery from destruction caused by both natural and human-made disasters. Emergency response teams are now using technologies including drones, satellite imagery, social media, and robotics to aid their response to unfolding disasters. Firefighters are equipped with durable protective equipment and go through comprehensive, high-tech training. Additionally, buildings are now outfitted with advanced fire and smoke detectors [1, pp. 7]. Despite these improvements, firefighting remains one of the deadliest jobs in the world [2].

In the last 40 years, the occurrence of structural fires has more than halved, yet the death rate per thousand home fires has remained stagnant [3]. According to the National Fire Protection Association (NFPA), continuous progress has been made to prevent fires; however, data indicates that structural fires are more lethal today than they were 40 years ago. Although equipped with protective gear, an average of 70 firefighters were killed every year from 2015 to 2017 from extreme heat and explosions [4].

The area in which firefighters carry out their operations, known as a fireground, is a dangerous and constantly changing environment. Currently, operational decisions at a fireground are made by an Incident Commander (IC). The IC is typically a senior member of the crew that makes decisions about tactics and resource management primarily based on their past experiences and instinct. Currently, decision making on the fireground is limited by the collection of available data. Real-time data about the building, fire, and firefighters would help ICs make better-informed decisions. A strategy to improve the IC's decision making would be to collect and integrate information from a wide range of databases and sensor networks, both within and beyond the fireground. According to the National Institute of Standards and Technology (NIST), the addition of "Smart" technologies to firefighting would "enable [considerably] better situational awareness, predictive models and decision making." [1, pp. 6]

This emphasizes the need for a "Smart" system to facilitate and improve the way fire situations are currently addressed. In Worcester, Massachusetts, firefighters have a particular need for technologies when working in old manufacturing buildings. Worcester is no longer a primarily industrial city; therefore, many of its factory buildings have been repurposed as restaurants, stores, and office spaces. These renovations have made large buildings compartmentalized, which makes it more complicated for firefighters to navigate them. In order to assist firefighters, a robot could be sent into the compartmentalized building ahead of firefighters to create and send back a map of the area in real time. This robot would allow firefighters to have a better understanding of the building's layout and environment, reducing the risk of firefighter fatalities.

# 2 BACKGROUND

Firefighting is one of the most dangerous professions due to its unsafe and unstable work environment. Firefighters may be required to operate under conditions with a high level of uncertainty and must make time-critical decisions using insufficient information [5]. This chapter will discuss different types of enclosed environments in firefighting, current problems in the field, and leading causes of firefighter injuries and fatalities.

## 2.1 Firefighting Environments

The challenges faced by firefighters vary based on the environment and circumstances of the fireground. These are directly related to the fire department's location and available resources. This section explores some of the issues that are faced in modern structural fire environments.

### 2.1.1 Structure Characteristics

As discussed in the Introduction chapter, structural fires have become more dangerous even though fire prevention technology has advanced. As shown in Figure 1, the number of home structure fires reported over the last 40 years has decreased by more than 50%, which indicates that fires are becoming more preventable.

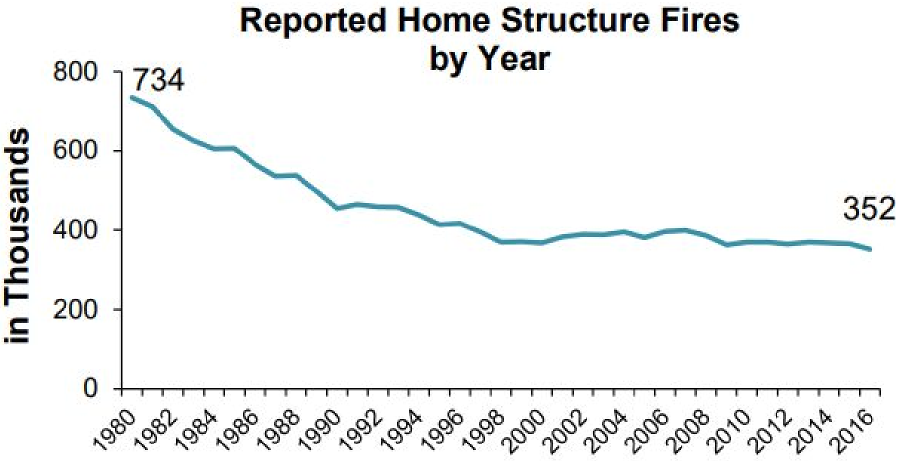

*Figure 1. NFPA, Reported Home Structure Fires by Year [6]*

This decrease is the result of cities enforcing stricter fire safety codes and other building regulations to minimize risks and prevent fires. Additionally, modern homes and businesses are equipped with advanced fire and smoke detectors. Despite the reduced occurrence of fire, Figure 2 shows that the number of deaths per thousand fires has stayed roughly the same since 1980.

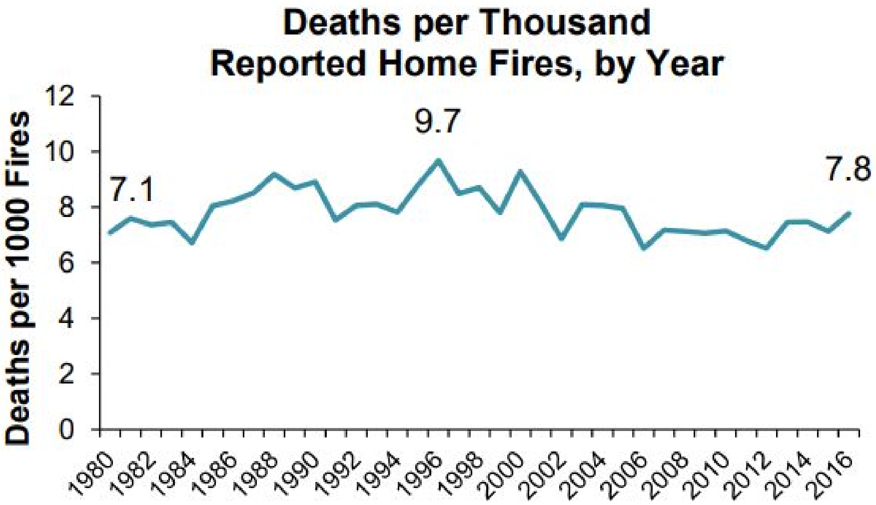

*Figure 2. NFPA, Deaths per Thousand Reported Home Fires by Year [6]*

Due to the use of new materials for construction and furniture, modern residential fires are more difficult to escape and more likely to result in flashovers. Unlike properties in the 20th century, modern buildings have replaced natural materials (e.g. cotton and wood) with lightweight synthetic materials (e.g. polyester and plastic), which burn more quickly and emit gases that are more hazardous [7]. Although synthetic materials pose greater risks when burned, they are still commonly used because they are less expensive and more durable than natural materials. The same applies to wall linings (e.g. drywall), which are thinner today and, therefore, easier for fires to penetrate [8].

NIST collaborated with Underwriters Laboratories (UL) to create a video [9] that compares the flashover rates (see Section 2.2.1 for more details about flashover) between a modern room furnished with synthetic materials and a "legacy" room furnished with natural materials. In less than ten minutes, a small fire in the modern room became a flashover while the legacy room completely ignited in triple that time. The additional danger caused by synthetic materials cannot be prevented by firefighters, so efforts must be made to improve firefighting to match the growing danger.

### 2.1.2 Enclosed Structures

An enclosed structure is an environment with very few windows or doors that cannot provide for immediate ventilation and emergency evacuation. In 2005, William R. Mora's Firefighter Disorientation Study found enclosed structures to be one of the most common sources of firefighter disorientation, and subsequently firefighter fatalities [10]. Basements and high rise buildings are both enclosed structure environments that often present challenges for firefighters when extinguishing a fire.

**Basement fires** are not only considered to be one of the most challenging operations to encounter, but they are also known to result in property loss and fatalities. Firstly, they are difficult to identify because the fire may appear to be coming from the ground floor[1]. Secondly, basements are difficult to access as smoke and heat builds up immense pressure that forces firefighters away. Because many basements have no walls or doors and the contents of a basement are often highly flammable, fires can develop rapidly and egress routes are limited. Lastly, basement fires can be very dangerous as basement ceilings are susceptible to collapse during a fire bringing risks to both firefighters on the ground floor as well as the basement [11].

**High-rise building (HRB) fires** pose two types of challenges for firefighters both in and outside the building. The main challenge presented to firefighters is the height of the building. For active fire fighting outside the building, equipment does not always reach the top floors. There is an upper limit on the amount of water pressure that can be applied by fire engine hoses which means water cannot reach the upper floors of HRBs. Additionally, firefighters inside HRBs have to carry heavy equipment up many flights of stairs while simultaneously evacuating any remaining occupants [12]. Once a firefighting unit is at the source of the fire, the second challenge is to fight it. Fires in high-rise hallways are problematic because they are defined as enclosed spaces (i.e., they are long, and they lack windows and open doors). According to Mora's 2005 study, survivors of high-rise fires have described flashovers as "blowtorch-like" due to the winds blowing into the fire from an opened hallway door [10].

### 2.1.3 Warehouses and Large Compartmentalized Buildings

Another type of environment that is difficult for firefighters is warehouses and large compartmentalized buildings. Deputy Chief Martin Dyer of the Worcester, MA Fire Department (WFD) identified that the WFD struggles with large compartmentalized buildings because of their unpredictable layout. Although compartmentalization hinders a firefighter's ability to combat a fire, the design is adopted in modern buildings as a passive fire fighting technique [13]. Subdividing buildings into a number of compartments prevents the rapid spread of fire, reduces the chances of fires growing, and limits the damage done to a building [14].

In Worcester, these large compartmentalized buildings are often old manufacturing buildings that have been renovated into new spaces for a variety of different businesses. The building layout firefighters may expect based on records in their databases may be drastically different than the current layout of the building. Deputy Chief Dyer described the building layout as a maze where

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[1] The ground floor is considered to be the floor above the basement. It is generally the level of entry.

some firefighters can become so lost and disoriented that they cannot find their way out. This description is consistent with the Worcester Cold Storage and Co. fire on December 3, 1999. This fire resulted in the deaths of six firefighters. These firefighters got disoriented and lost on the upper floors of the building. According to the NFPA records, this structural fire was the first to claim six firefighters where neither building collapse nor explosion were the main cause of the fatalities [15]. Although there has not been a warehouse fire as fatal as this one, the WFD continues to struggle with fires in large compartmentalized buildings.

## 2.2 Problems in Firefighting

Despite thorough preparation, firefighters continue to face challenges while operating in structural fires. These challenges are the result of uncertainties of structural integrity, unpredictability of fatal events such as flashovers or backdrafts, and simply getting disoriented and lost when entering buildings with unknown layouts.

### 2.2.1 Flashovers and Backdrafts

Flashovers and backdrafts are two dangerous events that can occur during a fire. Both situations can occur without significant warning, and that unpredictability poses a danger to the lives of firefighters.

A *flashover* is a rapid transition of fire from the growth stage into the fully developed stage in which the temperature rises exponentially as shown in Figure 3 [16]. It is the physical event in which the temperature of the room has reached a critical point (approximately 500 ºC) causing objects in the room to dry out and emit flammable gases. When this occurs, everything in the room will instantaneously burst into flames causing a rapid increase of temperature. Flashovers are typically contained in one room. Currently, firefighters attempt to anticipate the occurrence of flashover by looking at the smoke above them. If the smoke is ignited, it means a flashover is about to occur and they need to evacuate the room immediately.

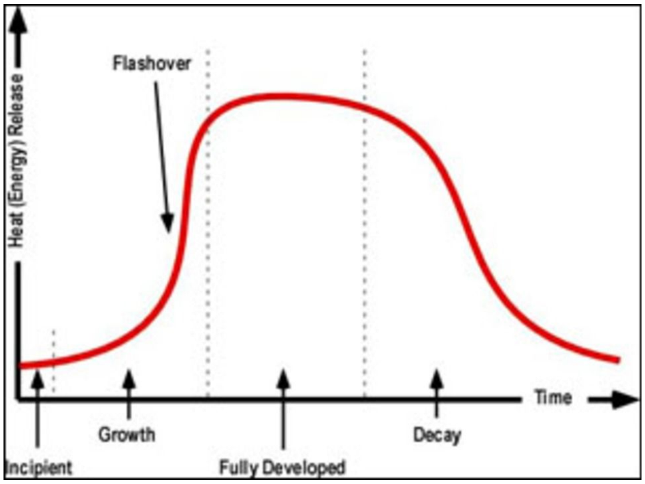

*Figure 3. Stages of a fire in an enclosed structure [17]*

A *backdraft* is an explosion that occurs when a large quantity of additional oxygen is introduced to a smoldering flame with a temperature great enough to ignite the added oxygen. Additional oxygen can be introduced into the system by a crack in the structure's exterior or by an opened window or door. A backdraft also involves the deflagration, or rapid combustion, of flammable products upon mixing with air. Backdrafts are more difficult to predict than flashovers because they happen quickly. Firefighters are trained to anticipate backdrafts by watching smoke patterns. If the smoke is being sucked into a room rather than flowing out, that means there is low pressure in the room and a backdraft may occur. Unlike a flashover, a backdraft can affect an entire floor of a building and even cause the building to collapse [18]. Figure 4 shows the point at which backdrafts are likely to occur in relation to the heat release in the room.

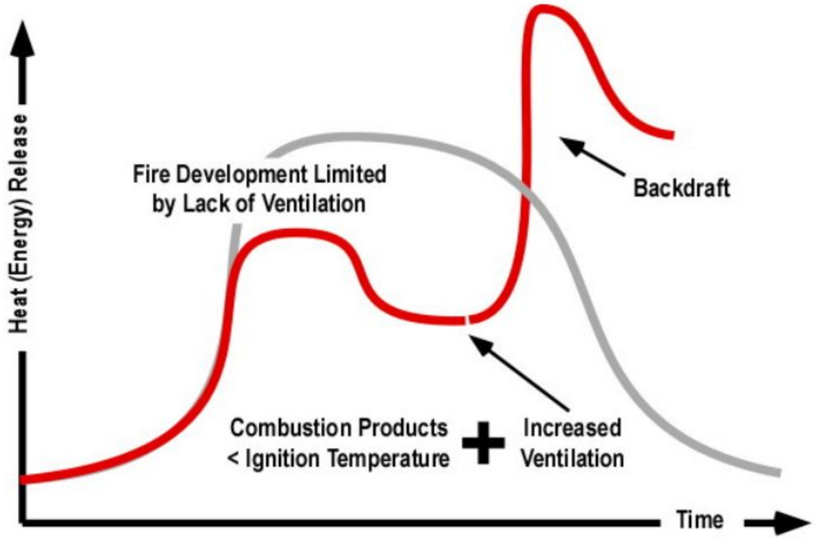

*Figure 4. Occurrence of backdraft [18]*

### 2.2.2 Disorientation

One of the largest threats to firefighter safety is getting lost in a hostile environment. Firefighters typically do not know the layout of a building before they enter it which can lead to confusion and disorientation. William R. Mora wrote an article in "Understanding and Solving Firefighter Disorientation" about a study he conducted between 1999 and 2001 [10]. Mora found that, in general, firefighters who become lost or disoriented in a fire tend to follow a disorientation sequence which leads to fatalities or serious injuries. The sequence involves the following steps or scenario:

1. Fire in an enclosed structure with smoke showing
2. An aggressive interior attack[2]
3. Deteriorating conditions such as Prolonged Zero Visibility Conditions (PZVC)[3], flashover, backdraft, or structural collapse
4. Handline[4] separation
5. Disorientation
6. Serious Injury or Firefighter Fatality

Although this article was written in 2003, firefighters continue to repeat this sequence today. From Deputy Chief Dyer's experience in the field, he stated that disorientation is common in large compartmentalized buildings with unknown layouts. Nevertheless, by understanding the steps of the sequence, a solution can be implemented to reduce the risk of fatalities or injuries. Since the *deteriorating conditions* step has a direct affect on a firefighter's orientation, an optimal solution would be to preemptively avoid or detect those conditions.

## 2.3 Temperature and Location

In a fireground, fire and smoke can have a direct impact depending on where a person is located. This section will explore how temperature changes in an enclosed structural fire and will determine the most optimal place to safely collect information.

When a room catches fire, the flame will burn upwards towards the ceiling which, in turn, creates a very unevenly distributed heat flux in the room. Below, Figure 5 shows a typical example of a residential fire inside a living room just a moment before the occurrence of a flashover. As shown in the bottom left corner of the heat map, the source of fire located in a corner of the room creates a flame that burns upwards causing the ceiling to accumulate heat.

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[2] An aggressive interior attack is also known as an offensive attack.

[3] PZVC is defined as 15 or more minutes of zero visibility after heavy smoke fills the environment. This was a big problem during the Cold Storage fire in Worcester, MA.

[4] A handline is a hose. Firefighters are trained to hold onto the hose so they can follow the hose out of the building should they get disoriented [31].

Generally, before a flashover occurs, the floor has a temperature below 140ºC, while the ceiling has a much higher temperature which can go up to 500ºC [19].

Hence, a sensing device should operate on the floor to safely and accurately collect information. Most modern integrated circuits have a max operating temperature between 70ºC and 125ºC [29]. By placing the device at the region of lowest temperature, it gives the advantage of the least challenging heat insulation and design requirement for the device.

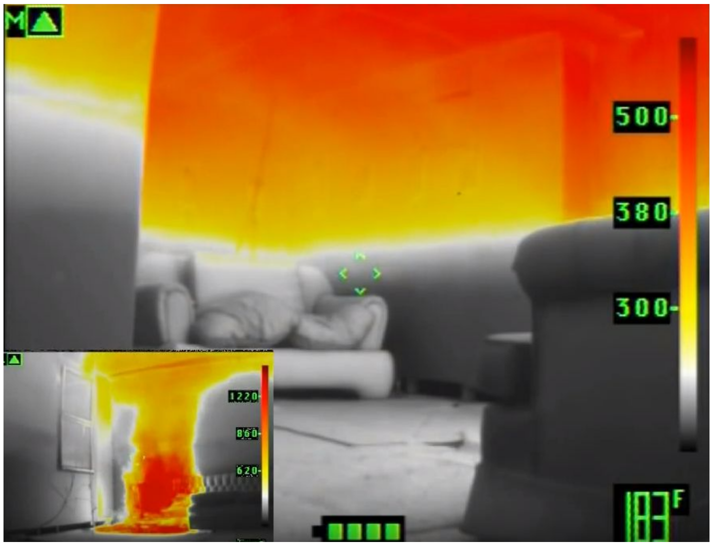

*Figure 5. Heat Flux Distribution in Degrees Fahrenheit of a Burning Room [20]*

## 2.4 State of the Art

Currently, many robotic solutions exist that can aid workers in public safety jobs. Robots are machines that are commonly used to replace humans in labor intensive, repetitive, and dangerous tasks [21]. Without prior information on the building layout during a structural fire and without real-time information on the current states of firefighters and the environment, firefighters are always putting their lives at risk when entering a fireground. While robotics can mitigate the risks posed to firefighters and the victims of a fire, most robotic solutions lack spatial compactness and dexterity.

### 2.4.1 Hoya Firefighting Robot

In 2009, the South Korean Hoya Robot Company designed a compact firefighting *spy* robot (Figure 6) that could be thrown and withstand a fall impact of 15 meters high, as well as withstand temperatures up to 160ºC for a 30-minute duration. The robot can be easily held by hand as the chassis has a diameter of 12.5 centimeters and weighs approximately 2 kilograms. By using sensors to monitor the environment (measuring temperature, oxygen, and carbon dioxide concentrations) and having the ability to recognize voice, this remote controlled device is an efficient means of exploring an unknown layout and providing significant information to firefighters to plan their actions accordingly [22][23]. Additionally, both the *tmdwl* [24] and *hoyarobot* [25] YouTube channels have videos to support the robot's functionality and demonstrate the device operating side-by-side with actual firefighters [26].

*Figure 6. Hoya Firefighting Robot Chassis [22]*

Although this device has promising functionality, there is no information regarding progress on this product after 2010. Nonetheless, the development and testing of this device demonstrates that this is a demand in the public safety sector. Considering that technology has progressed significantly since 2010, the current project may be able to resolve the problem more efficiently and may be more impactful.

### 2.4.2 ArchiBot-M & ArchiBot-S

DTB Fatec, a Korean robotics company focused in developing technology for field robots in the area of firefighting, has engineered the ArchiBot-M and ArchiBot-S series of robots[5]. ArchiBot-M, shown in Figure 7, is designed to be sent into inaccessible fire sites such as large buildings, tunnels, or storage facilities to check for explosive or combustibles, and guide firefighters to sources of fire. This robot has a suspension system that allows it to ascend and descend stairs. The robot is also waterproof and is able to withstand high temperatures. It weighs 45 kg, and it has an operating time of two hours. The maximum velocity is 20 km/hr.

*Figure 7. ArchiBot-M [27]*

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[5] http://www.drbfatec.com/frd_center/fighting_m.htm

ArchiBot-S, shown in Figure 8, is designed to be sent into inaccessible and dangerous places involving underground areas. It is designed to inform firefighters of geographical information, locations of trapped people, and burning sites. This robot is designed to be capable of rotating around in a narrow space, including ascending and descending stairs. This version also supports operation in high temperatures and has waterproof capabilities. It weighs 40 kg and provides one hour of operation [27].

*Figure 8. ArchiBot-S [27]*

### 2.4.3 Firo-S

IZ Holding is a manufacturing company in Singapore which has a security division focused primarily on robotics and surveillance systems. Among other products, IZ Holding has developed Firo-S [28], a firefighting robot that aims to operate in burning sites to obtain geographical information, detect humans, and track fire sources. The design includes a cooling system that allows the robot to operate at 500ºC for up to one hour. It has a built-in thermal image camera for search and rescue (S&R) operations and fire source detection. The robot, shown in Figure 9, is remotely controlled from a laptop that is equipped with a supporting software for operation. It weighs 40 kg and it can operate for up to 4 hours.

*Figure 9. Firo-S and its GUI [28]*

## 2.5 Problem Statement

When engaged in interior attacks on structural fires in compartmentalized buildings, firefighters are at risk of injury or death if they become disoriented or lost in the building's complex, unpredictable layout.

## 2.6 Customer Requirements

Based on the research conducted and the interview with Deputy Chief Martin Dyer of the Worcester Fire Department (WFD), the operational environment and details of a robot to assist the needs of the WFD were defined. The environment in which the assistance of a robot may be useful is converted manufacturing buildings because of their unpredictable layouts. The robot's requirements are:

- Quickly deployable
- Affordable
- Operate in the building ahead of firefighters
- The ability to survive the environment
- Evaluate and map the interior of the building
- Collect accurate environmental data
- Send data back to the Incident Commander (IC) via a simple, intuitive user interface
- Remotely controlled and easy to operate
- Long range communication
- Low power consumption
- The ability to transmit large amounts of data

The robot must be easy to deploy (i.e., take the shortest amount of time and effort possible) so that firefighters can focus on combating the fire rather than setting up the robot. Firefighters already have specific tasks they must complete in a time-limited scenario, so the deployment of the robot must be an insignificant task to add to their workload. It must also work ahead of the firefighters in order to not obstruct their normal tasks. To increase the adoption of the robot by more fire departments in the future, the robot should be affordable. Fire departments are government funded and typically have a very limited budget. The robot must also be able to survive the fire environment so that it remains useful. If the robot becomes damaged beyond use, it will no longer be providing data to improve the fighting of fires. The robot must also be able to be used for multiple fires because it will likely be too expensive to be disposable.

Advanced technology is not widely used in firefighting. At the WFD, for example, each dispatch vehicle is equipped with one iPad that displays data from the dispatcher such as the address of the alarm and the locations of nearby hydrants, but beyond this only non-electronic systems like whiteboards and clipboards are used. Deputy Chief Dyer recognized that beyond personal smartphones, many firefighters do not interact deeply with technology. Therefore, in order to be useful to fire departments, robot-gathered data must be analyzed by the system itself and presented in a manner that is simple, concise, and relates easily to technologies that firefighters are already familiar with. The robot will be remote controlled and easy to operate so that firefighters will have control of the robot at all times and will need minimal training to operate it. As discussed before, the robot must have little to no interference with how fire crews normally operate. Making it remote controlled will ensure that the activities of the robot do not conflict with the activities of the firefighters at any time.

Because the robot is designed for use in large, compartmentalized buildings, it will need to communicate information to the IC outside the building. The robot will be collecting and analyzing large amounts of data, so it will need to have the capability to send that data back to the IC. Additionally, the robot should be energy efficient so that the onboard battery will last long enough to map multiple rooms.

# 3 PROCEDURE

In order to complete the project, the team created a list of objectives and defined tasks to complete each objective. Additionally, the team was divided into smaller sub teams to focus on specific tasks. This section provides a more detailed outline as to how the project will be completed.

## 3.1 Project Objectives

The goal of this project is to develop a durable mobile sensing platform that can remotely navigate a fire environment, sense and map the status of areas of the building, and report the information to the Incident Commander in a concise and understandable way. The robot will be designed specifically for compartmentalized buildings or large converted buildings with unknown layouts. To achieve this project goal, the following objectives were created:

- Design and build a robot that is fire, shock, and ideally also water resistant
- Program the robot to be remote controlled
- Program the robot to report back gathered information wirelessly
- Demonstrate the robot's functions by remotely navigating a pre-mapped environment and overlay the provided map with a temperature map

## 3.2 Product Specifications

Based on the potential customer requirements, competitive value analysis, and market research, the final product will have the following specifications.

### 3.2.1 Mechanical and Materials Specifications

The robot will be designed to survive and operate in extreme conditions. Because the robot will be mapping the area rather than actively fighting the fire, it will not be in direct contact with the primary source of the blaze for extended periods of time. Therefore, the team will be designing the robot to operate in temperatures between 120ºC and 250ºC. The mechanical components of the robot should also tolerate impacts from deployment and unpredicted collisions with surrounding objects. Additionally, the presence of water is expected in the operating environment. The robot structure and outer layer should be durable and resistant to both heat and water. However, due to time constraints, the robot is not expected to be fully fireproof or waterproof.

The robot will be able to move throughout an environment that has small and large obstacles relative to the size of the robot. Videos of structural fires show that these environments are volatile and can be littered with obstacles. Small obstacles should not block the path of the robot, while larger obstacles will require the robot to navigate around them. Additionally, the robot will not be able to move between floors of a building and will only operate within an open floor space (i.e., it will not be equipped to move through closed doors or walls). Given the time constraints of this project, the team has simplified the operating environment to a single-level space (i.e., the robot will not ascend or descend stairs).

### 3.2.2 Electrical Specifications

The robot will have a primary printed circuit board (PCB) which will house a microcontroller or a field-programmable gate array and the peripheral boards to support sensing, mobility, and wireless communication. The sensing module will collect data about the temperature, infrared radiation (IR), and surrounding obstacles that the robot will encounter.

Utilizing these sensing technologies will provide a SLAM-like functionality to the robot. The driving module will consist of a driver circuit and motors. A safety module will be integrated in the robot which will be responsible for engaging or disengaging the brakes and indicating the operation status of the robot. The communication module will use transceivers that will operate at 2.4 GHz private wireless protocol. The purpose of this module is to wirelessly transmit the acquired data to a peripheral smartphone or tablet, which will be accessible by the Incident Commander (IC). Depending on the data given, the IC will inform the firefighters of potential hazards that exist or might arise in the fireground.

The robot electronics will be rated at industry standard operating temperatures (-40ºC to 125ºC) and are expected to generate minimal heat during operation. However, the mechanical structure of the robot will need to provide a robust seal around the electronics in order to prevent exposure to temperatures higher than 125ºC, as well as account for air flow to minimize the internal heat dissipation.

### 3.2.3 Software Specifications

The robot is expected to be remotely controlled and perform analysis of data gathered by on-board sensors. The analysis will allow the robot to generate temperature pattern data to plot onto a predefined map of the environment, constantly updating the current temperature readings and its rate of change. A user interface (UI) will be developed in order to process, evaluate, and display the data on a mobile platform. The UI will consist of a simple, user-friendly design to optimally convey the information and avoid confusion.

## 3.3 Subteams and Tasks

Based on fields of study, prior experience, and individual skill sets, the MQP team members are divided into three subteams:

- the Mechanical team
- the Electrical team
- the Software team

**The Mechanical team** will be responsible for 3D modelling and building the robot chassis, as well as conducting materials analysis and tests to determine which materials will be used to build the robot.

**The Electrical team** will be in charge of designing, testing, and evaluating the robot's electronics.

**The Software team** will be responsible for developing the algorithm to support mobility and data acquisition for the robot, as well as interfacing that information to an application.

## 3.4 Budget

Worcester Polytechnic Institute (WPI) grants $125 per undergraduate student for MQP research. With an additional $2,000 granted from Professor Pinciroli's research funds, the team will be operating within a budget of $2,625.

In order to avoid unnecessary spending, the team has appointed a treasurer to evaluate the necessity of all proposed purchases. Team members must submit a purchase request to the treasurer with the name and model of the component they need, as well as an explanation of why that part is required as opposed to a different, possibly less expensive alternative. The treasurer will then conduct their own research in order to verify the claims. They must inform the rest of the team of their decision, and if the team supports the purchase the treasurer will submit an acquisition form to Professor Pinciroli.

## 3.5 Assumptions and Exclusions

Given the time and budget constraints of the project, the following assumptions and exclusions for this project are thus defined:

1. **The Worcester Fire Department (WFD) is the primary customer.** With Professor Pinciroli's contacts within the department and the department's physical proximity to the Worcester Polytechnic Institute (WPI) campus, the WFD is one of the team's most valuable sources of information from firefighters' perspectives. A WFD Deputy Chief has already proffered information about the department's organizational structure, experiences, technological capabilities, and budget; therefore, many of the team's initial decisions were made with the WFD in mind. The WFD has also expressed willingness to test the project's final product during their training simulations.
2. **The robot may be thrown or placed on the ground.** The robot will be designed assuming that it can be deployed in different ways based on the situation. The robot will be able to begin driving and other functions from either a placed position on the ground or from its landing position after being thrown.
3. **The robot will only operate on a single level.** The robot will be designed to explore and map only a single floor (i.e., it will not be able to ascend or descend stairs). Multi-level operation may be a goal for future iterations of this project.
4. **The robot will not face completely obstructed paths.** For the purpose of development, the team is assuming an environment without closed doors and other such obstructions.
5. **The robot will not have a jumping mechanism.** Though the possibility has been explored, the ability to jump is not crucial to the robot's ability to navigate. It has thus been excluded in favor of more essential functions.
6. **The robot will not include swarm integration.** While ideally this robot will eventually be part of a disaster relief swarm, it is unrealistic to focus on swarm capabilities without first having an individual robot.

## 3.6 Issues and Risks

This project is required to be completed in a 21 week period, consisting of three seven-week stages. It is expected that the team will face critical challenges that will change the progress estimations specified in the Gantt Chart.

The team spent the first stage defining and shaping the project scope and objectives. It required individual research from each member in order to acquire fundamental information for the team to proceed further with the project. During the next stage, the majority of the team members will be taking a Software Engineering class which will be a considerable time commitment. During this stage, the team is expected to deliver a finalized design of the following:

- Robot electronics (i.e., block diagram, schematic, and simulations)
- Mechanical frame and its associated mechanisms or housing
- Mobility algorithm (i.e., flowchart and preliminary code or pseudocode)

However, the design process will require intensive research and innovative approaches in all associated disciplines. One of the major challenges involves building a mechanical body that can withstand impact, fire, water, and steam. This goal is subject to compromise based on the progress and team member capabilities of delivering such objective. Additionally, the second major challenge involves designing a sensor fusion based system to support sensing, navigation, and mapping in a smoke-filled or fire environment. Both the mechanical body and the sensor fusion based system are expected to contribute to the majority of the cost. Considering that each team member will be occupied with other classes, extensions of task deadlines are expected to occur during this stage.

In the beginning of the third stage, the robot’s parts are expected to be delivered. The team will focus on building and testing each component of the robot individually. The subteams will work together to build a fully integrated system and to ensure functionality. The interface between electronic modules as well as merging the software into the robot are subject to unpredicted complications. A major challenge at this stage will be to accomplish real-time data processing and conveying that information to an IOS or Android platform application.

Overall, the individual, subteam, and team tasks and milestones will be prone to changes during the development stages of this robot. However, this will not affect the end goal of the project. By the end of the 21 week period, the team is expected to deliver a fully functioning prototype of the robot.

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