Residential Autonomous Fire Fighting Robot Smart Home System

ECE 4011 Senior Design Project

Section A05, First Response Fire Brigade

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Executive Summary

The goal of the project is to develop a robot that can respond to fires within a home before first responders have time to reach the scene. The system will also report the location of the fire within a house's floor plan, video stream, and other important data or details on the incident to first responders. The First Response Fire Brigade team believes that this project will help bring about meaningful innovation to home fire safety by shortening first response time and reducing human risk. Currently, an average of 7 people die and 30 people are injured every day [1] from house fires in the United States, and this project stands to reduce these numbers.

A fire can spread from a small flame to encompassing a home in a manner of minutes. This means that early fire detection combined with even rudimentary fire suppression during a fire's early incipient stage may buy very valuable seconds or minutes for residents and first responders. This extra time may be the difference between hundreds of dollars or hundreds of thousands of dollars in property damage, or even the difference between life or death of residents, first responders, or pets.

This system will be easy to set up, making it possible for average, non technically inclined homeowners to install, configure, and operate. It requires little more effort than installing new fire detectors and a charging station, and could be done in a matter of hours by a contractor or even an unskilled homeowner or renter.

The fire detectors are expected to cost less than $25 for development models (parts only), and a similar amount as a retail product. The robot itself will likely cost $11,000 for parts for development, and much less for the final product, making the system an approachable and a worthwhile investment for the safety of one's home and family.

1. Introduction

An autonomous residential fire fighting robot smart home system is a home automation system that aims to detect, find, and suppress a fire within a home using a ground robot during the period of time before first responders arrive to the residence. The First Response Fire brigade team requests $560.80 to develop a prototype of the system which will consist of two custom-built fire detectors, a self-navigating and fire searching ground robot, and demonstration materials.

1.1 Objective

The objective of the project is to develop a prototype of an autonomous residential fire detection and suppression system, meaning that only battery-powered fire detectors and an equipped companion robot will be required to operate the system on one floor of any home given that the homeowner can supply a floor plan to the system. The robot will not be able to ascend/ descend stairs or open doors. The robot will sit in sleep mode within the home until operation is required, possibly on a charging/ docking station which currently does not exist for the Pioneer 3-AT model of floor robot and will not be included in the prototype system.

Initial fire detection will occur using a network of smart smoke detectors. Once smoke/ fire is detected, the robot will navigate to and search the house sector in question using an IR camera and computer vision algorithms to recognize flames and thermal sensors to avoid them. Lidar and path planning algorithms such as ROS 2D Navigation Stack will be utilized to localize the robot within the home's floor plan and avoid obstacles. The robot will use a embed-controlled mechanical system to initiate and aim the fire extinguisher's nozzle in direction of the flames in order to perform fire suppression. Feedback control will be used to counter the force of the fire extinguisher so that the robot can remain stable during suppression. Data collected by the robot during operation will be sent to first responders in order to assist their search and further suppression of the fire. Though the robot will have an emergency stop button, no other user interface will be present.

1.2 Motivation

On average, 7 people per day die in house fires in the United States. Even with the rigorous standards for fire safety in the US, fires in buildings were responsible for over 10 billion dollars of property damage in 2017 [1]. This project aims to lower these numbers by shortening the time between when a fire starts and when it is responded to. By introducing a new stage to fire response -- automated in-home suppression -- we hope to make it possible to reduce this loss by stopping or suppressing fires much faster than the fire department can, all without risking human life.

As it stands, even with an automated fire alarm system, the time between a detector going off and first-responders arriving at the location can be expected to be on the order of several minutes. In this time, the fire can transform from a contained, manageable flame to a life-threatening blaze. In the best case scenario, someone in the building notices the fire and is able to put it out before it has a chance to spread. However, this relies on several factors: a person must notice the fire in time; the person must know how to appropriately respond to the fire (and whether it is worth the risk to attempt to put it out); the person must know where to find a fire extinguisher and how to operate it. Though this situation happens often enough, it does not apply when no one is home, or when a fire extinguisher is inaccessible, or when there is no time to spare. Even if a person is able to put the fire out themselves, it puts them in danger to do so. This project will take away the burden, risks and complications of fires response from the occupants of the home, allowing them to focus on escaping the building. It offers all the benefits of early-stage fire suppression without requiring any human risk.

Another issue is that of information. Currently, a fire department knows very little about the fire before they enter the building. This system, with its network connection, localization, and cameras, can give firefighters a way to see inside the building, letting them assess how to handle the fire from a safe distance.

This product will improve the chances of survival in the event of a fire, minimizes risk for firefighters, and stands to reduce the physical impact of the fire substantially. It can help areas that are poorly served by their local fire department, or families worried about being able to evacuate everyone safely. It can add precious time to escape a dangerous fire, or even prevent it from getting dangerous at all. It offers a substantial value to homeowners, insurance agencies, and the fire department themselves. Insurance agencies may have interest in leasing such a system to homeowners with particularly valuable properties as it is estimated that home fires cost $7.7 billion dollars in property loss, excluding wildfires [1]. Though it will exceed the cost of a traditional smoke detector system by a substantial margin, it will be the only system of its kind and will offer functionality and peace-of-mind that other systems completely overlook.

1.3 Background

Though there is not a smart home autonomous, mobile fire suppression system on the market today, there is much research being done in the area of autonomous mobile robotics for indoor fire suppression. There are also other types of fire suppression tools on the market developed for both businesses and to assist firefighters. There are ceiling-fixed fire suppression torrents that utilize computer vision with IR cameras to suppress fires in warehouses. Fire departments can utilize remote-controlled armored ground robots to fight large, dangerous fires and aerial drones with computer vision capabilities to tack the spread of wildfires [2].

The essential building blocks for the prototype system focus mainly on autonomous navigation, artificial intelligence for object search, computer vision for fire recognition, and a network of embedded devices for the smoke detectors. Autonomous navigation is achieved using a lidar to localize the robot and the ROS Navigation stack which is part of the Robot Operating System (ROS), a linux-based framework agreed to be the state-of-the-art of robotics frameworks [3] as it provides a low-level communications infrastructure, an open-source robotics toolset for perception and navigation that is being continuously developed by the robotics community, and a powerful development toolset for debugging and visualization. Though modifications to the ROS navigation stack allow for simultaneous navigation and mapping (SLAM) of an unknown environment, navigation of a known map, such as a floor plan, is preferred for this application over performing SLAM since presence of smoke degenerates the accuracy of lidar data [4]. There are several ROS packages developed for map exploration and object search, Hector Planning in particular was developed over several iterations of a mobile robotics rescue mission competition and may be applicable to this application [5]. In the realm of flame recognition, there is an algorithm that can be used with infrared cameras that identifies flames from static heat sources by looking for bright objects with rapid time-varying contours [6].

2. Project Description and Goals

The team will design a system consisting of two types of components: two custom-built fire detectors and a modified Pioneer 3-AT robot. The goal of the system is to detect a fire within a room, navigate to the correct room while avoiding obstacles, search the room for fire, detect the fire, and aim the fire extinguisher to correctly suppress the fire. The battery powered smoke detectors will consist of a microcontroller with wifi networking capabilities, a gas/smoke sensor, and a temperature sensor. The modification to the Pioneer 3-AT robot will include installation of a Hokuyo lidar for navigation, installation of IR cameras for taking a stream of heatmap data, installation of a Jetson TX2 motherboard and GPU module for processing the IR camera stream to perform fire recognition, installation of an embedded system running a webserver that connects to the smoke detectors and wakes the Jetson board when required, and installation of a fire extinguisher with servos to aim the nozzle. The project goals include the following:

Smoke Detectors and Web Server

- Smoke detectors send signal over wifi to web server when fire is detected.
- Web server sends signal to wake jetson board for robot response.

Robot

- Accurately localize robot within floor plan regardless of starting position.
- Navigate to correct room for triggered smoke detector.
- Search room efficiently for fire while avoiding flames.
- Recognize flames and accurately detect fire position.
- Accurately aim extinguisher nozzle to fire position and spray a steady steam, stopping once fire is extinguished.

Time permitting, further stretch goals of greater implementation and design may be implemented. This includes integration of the robot and smoke detector network into an existing home security/management system, as well as adding video stream and control options via mobile application for the homeowner. The integration into existing home systems using the Z-wave communication protocol would greatly increase the capabilities of both the robot system and the home security system, such as allowing for more custom configurations, as well as providing more information to the emergency resources that the home security system would contact. Adding control options and video streams for the customer is very important but a large jump to implement as a whole mobile application would need to be developed. If time allows, development towards this application would be very beneficial by allowing full live monitoring by the homeowner.

3. Technical Specification

3.1 Smoke Detectors

Table 1. Smoke Detector Specifications	
Item	**Specification**
Microcontroller	ESP-WROOM-32
Operating Temperature	0°C - 120°C
Wireless	802.11 b/g/n 2.4GHz
Networking	MQTT over Wi-Fi
Operating Voltage	3.3V
Operating Current	80mA
Smoke Sensor	MQ-2 Sensor
MQ-2 to ESP32 Communication	Analog Voltage Input
Alarm Activation Threshold	500ppm

3.2 Robot and Central Hub

Table 2. Robot Specifications	
Item	**Specification**
Robot Type	Pioneer 3-AT
Max Payload	12 kg
Max Traversable Grade	35%
Robot Range	Autonomous Traversal of Single Story

Charge Time	12 Hrs
Supply Voltage	5V @ 1.5A or 12V @2.5A
Processing	Jetson TX2
Jetson Dimensions	87mm x 50mm
Fire Verification Ability	Positive Identification of Flame with OpenCv
Video Encoding	2 X 4k @ 30 Hz
Wireless	Onboard Wi-fi 802.11 b/g/n
Lidar	Hokuyo UTM-30LX
Lidar Range	30m
Obstacle Avoidance	Avoid Obstacles using Lidar
Coprocessor, web server	mbed LPC1768

3.3 Fire Suppression System

Table 3. Fire Suppression System Specifications (To be decided by ME's in Fall)	
Item	**Specification**
Fire Suppression Device	Fire Extinguisher
Fire Extinguisher Operation	Ability to sweep 270° back and forth and 90° up and down
Microcontroller	mbed LPC1768
Servo Control	PWM signal from mbed microcontroller

4. Design approach and details

4.1 Design Approach

This project will consist of three different modules, each of which has a hardware and software component. The fire detectors, the robot, and the central management server, an embedded device which will sit on the robot to wake the robot once a fire is detected. The role of the fire detectors is to monitor each room for smoke and heat and relay that information to the central server. The server monitors the data from the fire detectors (and the robot when it's active), provides an interface for homeowners and first responders, and activates the robot when necessary. The robot, when activated, will autonomously navigate to the room in which a fire was detected, locate the fire visually, and attempt to suppress it.

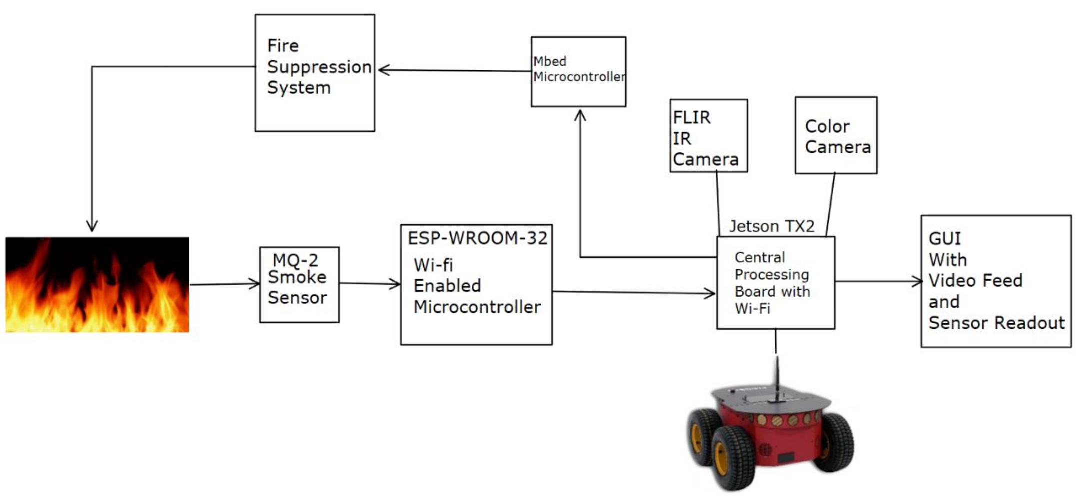


Figure 1. Block Diagram of full system view

4.1.1 Fire Detector

The fire detectors will be similar in many ways to a traditional residential smoke detector. They will be mounted to a wall or ceiling, be powered via 120v AC or an internal battery, and will have very little - if any -

physical interface. They will need to poll one to three sensors and communicate with the central management server, so a low-power chip with wireless connectivity is ideal.

4.1.1.1 Sensors

There are a number of different sensors which could be appropriate for a smart fire detector depending on acceptable price range. At the low end of the spectrum, which will be considered the minimum acceptable sensing equipment, is a traditional smoke sensor. This is only triggered after the fire has generated sufficient smoke to be detectable in the air in the room, so it may not offer early enough warning for the robot to reach the fire and suppress it. A more expensive option is optical detectors, which trigger based on light intensity at one or more specific wavelengths associated with flames of common substances. These optical detectors can be configured as a pixel array, giving an image-like reading of where the fire is localized. The proof of concept fire detectors are planned to employ a chemiresistor gas sensor (Hanwei MQ-2) to sense smoke and a low-cost infrared sensor to detect visible flames.

4.1.1.2 Networking

There are several wireless networking protocols available for use with household embedded systems, including Z-wave, Zigbee, and 802.11 WiFi as the top competitors. The former two offer much lower power modes of operation and can function in a decentralized mesh. The latter offers simpler integration with existing network infrastructure. Since the fire detectors will likely be wired into the house's electrical system, power consumption will not be particularly relevant, and the ease of deployment afforded by WiFi makes it more attractive than the other two alternatives. Connecting the detectors via WiFi enables them to communicate directly with any device on the network, making it possible for the user to interface with them directly if desired. It also allows the central server device to operate with just a traditional network interface, instead of needing to incorporate a Zigbee or Z-Wave adapter.

4.1.2 Robot

The robot will be a MobileRobotics Pioneer 3-AT platform, operated by an Nvidia Jetson TX2 computer with GPU module. It will need to be able to self-localize within a known map, navigate through the map with potentially unknown obstacles, search a space to locate flames, recognize flames, and control a fire suppressant system.

4.1.2.1 Navigation

The robot will operate with a provided static map based on the layout of the house and will use 2D LIDAR to localize itself within the map, identify, and avoid unexpected obstacles. The majority of the algorithms will be provided by the ROS Navigation stack, including cost mapping and global and local path planning. ROS plugins and custom nodes will be developed as necessary to handle sensor inputs and behaviors that are not supported by the provided libraries.

4.1.2.2 Fire Searching, Recognition, and Positioning

Once the robot reaches the room where the fire detector was triggered, it will need to locate the flames and aim the fire extinguisher at them. In order to do this, it will need to be able to recognize flames and determine their approximate location in space. Two stereo FLIR infrared cameras, providing depth perception, will be used to determine the position of the fire. One color camera may also be added to help augment the FLIR camera to discern generic heat sources, for example an open oven, from actual flame through the use of computer vision; however there are algorithms for infrared camera streams that recognize the moving nature of flames from static heat sources. This may prove infeasible, given the amorphous nature of the "object" being located, in which case an alternative method for discerning the position of the flame will need to be considered.

4.1.2.3 Fire Suppression

The robot will feature an aimable fire suppression system, which will consist of a mounted and encased pressurized fire extinguisher. A pair of servo motors will provide 2-axis aim for the extinguisher nozzle. Feedback control will be used to counter the force of the fire extinguisher spray stream and help the robot and spray stream remain stable. The exact model of servo that will be used is yet to be determined, however this issue will be assessed and decided upon by the mechanical engineering students joining this project in the fall.

4.1.3 Central Web Server

The physical implementation of this aspect of the project is completely certain, but the device used will either be a small embedded device or raspberry pi that is physically connected to the robot. It will connect to the fire detectors and the rest of the network over wifi, and will be able to power on the robot using a direct electrical connection using GPIO calls to the Jetson TX2. Once powered on, the Nvidia Jetson can be connected to a wireless connection, and the web server will keep track of the status of both the detectors and the robot while providing data and possibly a video stream to fire responders or the homeowner.

4.2 Codes and standards

The available wireless standards for networking are ZigBee, Z-Wave, IEEE 801.22 WiFi. Reviewing each standard characteristics led us to choose the Espressif ESP32 chip for the wifi smoke detectors. NFPA codes and standards also need to be adhered to. This is what led us to choosing to use an actual fire extinguisher, rather then trying to build a pump and a reservoir to manually pump fire suppressant onto the fire. Lastly, the Robotic Operating System (ROS) has a standard for how ROS packages are written which will be followed for our project's software development as it will be deployed as a ROS package. Also for any open source software that is used, like ROS, its license must be included in our project.

4.3 Constraints, Alternatives, and Tradeoffs

There have been a number of limitations imposed on this project to maintain a realistic scope, and several tradeoffs have been implemented to accommodate.

To restrict cost and potential development time for the robot chassis itself, the scope for the proof-of-concept has been restricted to handling fires in single-story areas without closed doors. A multi-story space would require the robot to traverse stairs, and closed doors must be breached in some manner. By restricting the project to exclude those scenarios, a cheaper, less mobile platform can be used, and no development time must be spend on a manipulator for door handles.

A tradeoff that our team encountered was the method of localization used when the robot is navigating to the detected fire location and searching for fire. Our first inclination was to explore the option of using lidar and a Simultaneous Localization and Mapping (SLAM) algorithm for localization during navigation. However, upon further research, we realized that lidar performs poorly in smoky conditions and so our team decided to switch from a SLAM approach to performing navigation by localization via a fixed map of the home floor plan preloaded to the robot beforehand. The tradeoff for this design decision was having to completely change the method of navigation and obstacle avoidance in order to increase system reliability.

5. Schedule, Tasks, and Milestones

The Gantt chart in Appendix A shows the building blocks of the project as well as the schedule that will be adhered to complete these building blocks. The PERT chart in Appendix B shows task dependencies with optimistic, most likely and pessimistic time estimates for each task. Using the PERT chart, the critical path was determined to be 85 days.

The critical path contains the tasks that are likely to be the riskiest. These tasks are mostly associated with data processing for fire detection, because data processing is computationally intensive, and will require rigorous testing for optimization.

6. Project Demonstration

To validate the specifications of the project, the demonstration needs to show fire detectors successfully communicating with the robot, the robot navigating the house with a preloaded fixed map while avoiding obstacles, correctly identifying the location of the fire using computer vision, and finally using a simple sprayer or a pressurized fire extinguisher to respond to the fire. It will not be possible to demonstrate all of these steps live during the Design Expo because of safety concerns. However, a video will be recorded showing the full operation of the robot.

Indoor navigation, obstacle avoidance and object search of the robot will be conducted at a team member's house, which has the needed layout. Instead of starting a fire, a Bunsen burner will be used to trigger the sensors. A red point laser will then be used to indicate that the fire location has been found, instead of using a sprayer or a fire extinguisher.

An obstacle course made out of plywood will also be built outdoors, where a controlled fire will be started. Fire detectors will wake up the robot, which will then start navigation around the constructed plywood space. The navigation process, as well as the object detection, will be visualized using the ROS 3D visualizer rviz. Finally, fire will be responded to using a fire extinguisher or a spray.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

Following the fact that, on average, seven people died in U.S. home fires per day, according to the report published by the National Fire Protection Association (NFPA), between 2012 to 2016, 355,400 incidents of home structure fires are responded annually, causing an annual average of 14,230 civilian fire deaths and injuries, and $6.5 billion in direct property damage [7]. Furthermore, according to the data collected by NFPA, 25% of residential fire spread beyond room of origin [8], which indicate the need of an efficient residential first responder. Combining with the data that 42% of all reported firefighter injuries occurred at the fire ground, which include muscular pain, wound, cut, bruise, bleeding, smoke inhalation, and many more physical strain [9], the need of robotic fire responder seem to be even more prominent. Some companies do offer similar product, such as the Turbine Aided Firefighting machine (TAF 20), which cost AUD$ 310,000 (~USD$ 230,000) to build [10]. However, this robot is designed to be suitable for professional use rather than residential, since it needs to be piloted by a trained operator, such as the fire fighter, through remote control, has a size of approximately a golf cart, and, not to mention, the high building cost that might not fit commercially. These in turn make our proposed prototyped to be the ideal product for residential use since it is smaller and autonomous.

7.2 Cost Analysis

The total cost of developing an autonomous residential fire fighter robot prototype is estimated to be $49700.80 involving a team of 6 engineers being paid with typical engineer starting salary, which was assumed to be $70,000.00. Factoring out the labor cost, the total cost in parts and components needed while developing the prototype are estimated to be $560.80, which is lower than the true cost of $11,416.65. This reduction of cost was contributed by some of the expensive components that are available as loanable or owned resources. Table 4 and Table 5 summarized the cost of developing the prototype:

Table 4. Prototype Components Cost

Item	Type	Qty	Unit Price ($)	True Cost ($)	Actual Cost ($)
Fire Detector					
ESP-WROOM-32 [12]	Microcontroller	2	3.80	7.60	7.60
Grove MQ-2 [13]	Smoke sensor	2	6.90	13.80	6.90
Fire Suppression System					
Mbed LPC1768 [11]	Microcontroller	1	54.95	54.95	Owned
FLIR Lepton 3.5 [17]	Thermal Camera	2	239.00	478.00	478.00
HiTech HS-322HD [16]	Servo	2	11.99	23.98	23.98
Robot					
Hokuyo UTM-30LX [15]	Lidar	1	4,500.00	4,500.00	Loaned
Nvidia JETSON TX2 Developer Kit [14]	Motherboard with GPU on board	1	299.00	299.00	Loaned
Pioneer 3-AT [18]	Mobile Robot Base	1	5,995.00	5,995.00	Loaned
Miscellaneous					
Plywood 19/32 in. x 24 in. x 4 ft	Demo Supply	4	7.33	29.32	29.32
Bunsen Burner	Demo Supply	1	15.00	15.00	15.00
			Total Cost ($)	**11,416.65**	**560.80**

Table 5. Prototyping Labor Cost		
Prototype Development Task	**Labor Hours**	**Labor Cost ($)**
Robot Navigation Design	280	10,080
Fire Search and Detection Infrastructure	320	11,520
Fire Detection Processing Implementation	350	12,600
Servo Control System Design	130	4,680
Fire Extinguisher Enclosure and Mechanism Design	60	2,160
Testing/Debugging	65	2,340
Group Meetings	160	5,760
Total	**1,365**	**49,140**

To estimate an appropriate selling price for this product, assumption is made that 5000 units of the autonomous robots are to be sold in a period of five years, and the total development cost of $49700.80 are to be amortized over all of these units. 30% of Fringe benefits and 120% of overhead will also be factor in. In addition, it is estimated that $500,000.00 sales expenses will be spent to market the product. It is expected that a profit of $1.257.74 (5% of the total cost) is to be made from each unit.

Table 6. Product Selling Price	
Development Component	**Cost ($)**
Assume: 5000 units sold in 5 years	
Parts Cost	56,861,650.00
Labor Cost (Assembly and Testing)	45,000.00
Fringe Benefits, % of Labor	13,500
Subtotal	56,920,150.00

Overhead, % of Material, Labor, and Fringe	68,304,180.00
Subtotal, Input Cost	125,224,330.00
Sales Expense	500000
Amortized Development Cost	9.94
Subtotal, All Cost	125,774,031.00
Profit	6,288,701.54
Selling Price	**26,412.54**

8. Current status

Currently, most of the essential components needed for the project are obtained, such as the FLIR camera, pioneer mobile robot and jetson board. Since this is still in the beginning stage of the project, not much progress have been made to the main structure of the robot. Some small sub-tasks, such as the smoke detector assembly, are assembled and ready to be used on the robot. Experiments and trials with the web servers have also been attempted, such as using MQT to pass message with NodeRED . The essential ROS 2D navigation tutorial with pioneer robot have also been taken and completed by the navigation team.

9. Leadership role

Team Lead/Navigation Lead: Natalie Rakoski

Network Integration Lead: Zachary Elliott

Documentation/Control System Design: Ricky Marscel

Sensor Integration Lead/Webmaster: Chris Wang

Expo Coordination/System Integration: Thomas Wyatt

Computer Vision Lead: Deniz Bozkurt

10. References

[1] E. Evarts, "Fire Loss in the United States During 2017," *nfpa.org,* 2018. [Online]. Available: www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/US-Fire-Problem/osFireLoss.pdf

[2] B. Lattimer, "Robotics in Fire Fighting," *sfpe.org*, 2015. [Online]. Available: https://www.sfpe.org/page/FPE_ET_Issue_100/Robotics-in-Firefighting.htm. [Accessed: April 18, 2019].

[3] E. Tsardoulias and P. A. Mitkas, "Robotic frameworks, architectures and middleware," 2017. [Online]. Available: https://www.researchgate.net/publication/321180717_Robotic_frameworks_architectures_ and_middleware_comparison. [Accessed: March 1, 2019].

[4] J. W. Starr, B. Y. Lattimer, "A Comparison of IR Stereo Vision and LIDAR for use in Fire Environments," 2013. [Online]. Available: https://ieeexplore.ieee.org/document/6411591. [Accessed: March 5, 2019].

[5] S. Wirth, J. Pellenz, "Exploration Transform: A stable exploring algorithm for robots in rescue environments," 2013. [Online]. Available: https://www.uni-koblenz.de/~agas/Documents/Wirth2007ETA1.pdf. [Accessed: March 7, 2019].

[6] A. Çetin, B. Merci, O. Günay, B. Töreyin and S. Verstockt, Methods and techniques for fire detection. Academic Press, 2016.

[7] M. Ahrens, "Home Structure Fires," *nfpa.org*, Dec. 2018. [Online]. Available: https://www.nfpa.org/News-and-Research/Data-research-and-tools/Building-and-Life-Safety/Home-Structure-Fir es.

[8] M. Ahrens, " Reported Structure Fires by Extent of Fire Spread, Occupancy and Loss Rates," *nfpa.org*, Mar. 2013. [Online]. Available: https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Building-and-life-safety/OSStr uctureFiresbyExtentofFlameSpread.ashx?la=en.

[9] B. Evarts and J. L. Molis, “United States Firefighter Injuries 2017,” *nfpa.org*, Nov. 2018. [Online]. Available: https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Emergency-responders/osffinjuries.pdf.

[10] S. Gerathy, “Australia's first fire-fighting robot unveiled for summer bushfire season,” *adc.net.au*, Dec. 9, 2015. [Online]. Available: https://www.abc.net.au/news/2015-12-10/australias-first-fire-fighting-robot-unveiled-for-summer/7017660.

[11] “mbed - LPC1768 (Cortex-M3),” *sprakfun.com*. [Online]. Available: https://www.sparkfun.com/products/9564.

[12] “ESP32-WROOM-32,” *mouser.com*. [Online]. Available: https://www.mouser.com/ProductDetail/Espressif-Systems/ESP32-WROOM-32?qs=chTDxNqvsyltcwz%2FUUJDtQ%3D%3D.

[13] “Grove - Gas Sensor(MQ2),” *seeedstudio.com*. [Online]. Available: https://www.seeedstudio.com/Grove-Gas-Sensor-MQ2.html.

[14] “JETSON TX2 Education Discount,” *nvidia.com*. [Online]. Available: https://www.nvidia.com/object/jetsontx2-edu-discount.html

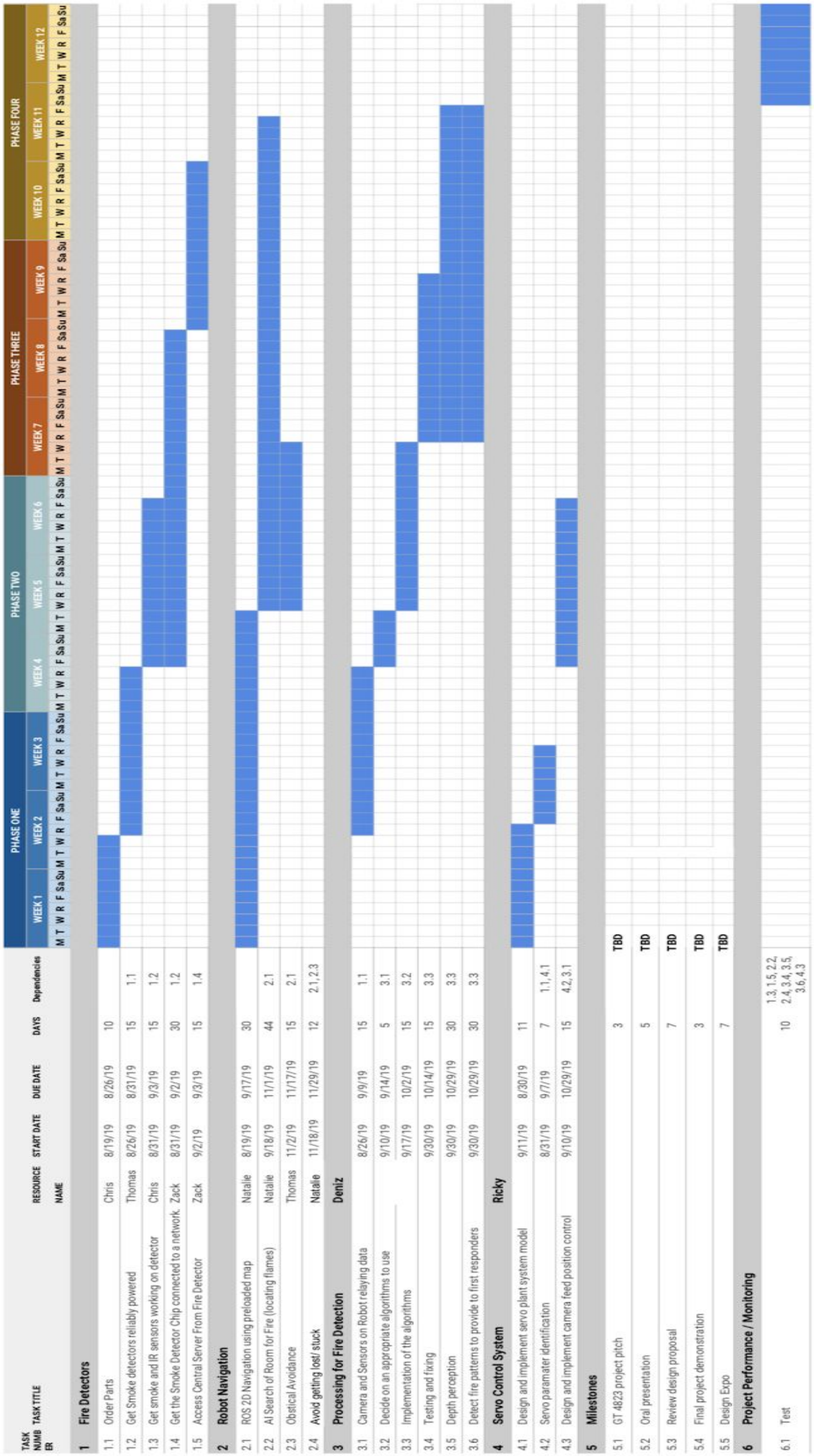
[15] “Hokuyo UTM-30LX Scanning Laser Rangefinder,” *robotshop.com*. [Online]. Available: https://www.robotshop.com/en/hokuyo-utm-03lx-laser-scanning-rangefinder.html

[16] “HS-322HD Standard Heavy Duty Servo,” *robotshop.com*. [Online]. Available: https://www.robotshop.com/en/hitec-hs-322hd-servo.html

[17] “FLIR Lepton 500-0726-01,” *digikey.com*. [Online]. Available: https://www.digikey.com/product-detail/en/flir-lepton/500-0726-01/500-0726-01-ND/6163867

[18] “Educational Price List,” *cse.sc.edu*, Nov. 11, 2004. [Online]. Available: https://cse.sc.edu/~matthews/Courses/510/Kits/EduPrices.pdf

Appendix A - Project Gantt Chart



TASK NUMBER	TASK TITLE	RESOURCE NAME	START DATE	DUE DATE	DAYS	Dependencies
1	**Fire Detectors**					
1.1	Order Parts	Chris	8/19/19	8/26/19	10	
1.2	Get Smoke detectors reliably powered	Thomas	8/26/19	8/31/19	15	1.1
1.3	Get smoke and IR sensors working on detector	Chris	8/31/19	9/3/19	15	1.2
1.4	Get the Smoke Detector Chip connected to a network.	Zack	8/31/19	9/2/19	30	1.2
1.5	Access Central Server From Fire Detector	Zack	9/2/19	9/3/19	15	1.4
2	**Robot Navigation**					
2.1	ROS 2D Navigation using preloaded map	Natalie	8/19/19	9/17/19	30	
2.2	AI Search of Room for Fire (locating flames)	Natalie	9/18/19	11/1/19	44	2.1
2.3	Obstical Avoidance	Thomas	11/2/19	11/17/19	15	2.1
2.4	Avoid getting lost/ stuck	Natalie	11/18/19	11/29/19	12	2.1, 2.3
3	**Processing for Fire Detection**	**Deniz**				
3.1	Camera and Sensors on Robot relaying data		8/26/19	9/9/19	15	1.1
3.2	Decide on an appropriate algorithms to use		9/10/19	9/14/19	5	3.1
3.3	Implementation of the algorithms		9/17/19	10/2/19	15	3.2
3.4	Testing and fixing		9/30/19	10/14/19	15	3.3
3.5	Depth perception		9/30/19	10/29/19	30	3.3
3.6	Detect fire patterns to provide to first responders		9/30/19	10/29/19	30	3.3
4	**Servo Control System**	**Ricky**				
4.1	Design and implement servo plant system model		9/11/19	8/30/19	11	
4.2	Servo paramater identification		8/31/19	9/7/19	7	1.1, 4.1
4.3	Design and implement camera feed position control		9/10/19	10/29/19	15	4.2, 3.1
5	**Milestones**					
5.1	GT 4823 project pitch				3	TBD
5.2	Oral presentation				5	TBD
5.3	Review design proposal				7	TBD
5.4	Final project demonstration				3	TBD
5.5	Design Expo				7	TBD
6	**Project Performance / Monitoring**					
6.1	Test				10	1.3, 1.5, 2.2, 2.4, 3.4, 3.5, 3.6, 4.3

Appendix B - PERT Chart