ABSTRACT
Uncontrolled wildfires pose a severe threat to federally protected areas, wildlife, and any nearby buildings. Despite the brave work done by our first responders, they cannot always reach the areas affected. Wind conditions can quickly engulf areas with fire, sometimes the terrain is unsuitable to navigate, and these are just some of the issues firefighters face while trying to contain fires. However, due to the increasing accessibility and affordability of reliable quadcopters, there exist a niche where swarm robotics could work hand in hand with firefighters in the front line. A quadcopter offers unparalleled benefits, they can fly over unsuitable terrain and have great mobility. In this paper we will introduce a prototype swarm robotic platform, based on existing quadcopter designs. The intention of this prototype platform is to aide firefighters in suppressing fires in areas they simply cannot reach, thus helping them tame uncontrolled wildfires. In order to accomplish this the platforms will have their own package of sensors designed for intelligent leader-follower swarm navigation and fire detection. In addition to the advanced package of sensors, the prototype will a portable fire extinguishing technology for fire suppression. Finally, we will conclude with a discussion on the future potential of this technology.

Keywords
Quadcopter, swarm robotics, wildfire, fire detection, extinguisher, leader-follower

1. INTRODUCTION
Unmanned Aerial Vehicles (UVA) technology has advanced rapidly over the last decade, just about anyone can pick up a controller and learn to successfully navigate a quadcopter with very little effort. Currently quadcopters have become so widely accessible and affordable that they can be found being operated by children and adults alike in any park. Currently commercially available quadcopters are designed for two primary purposes, flight and photography, this unfortunately limits their potential. This paper envisions using quadcopters for a greater function, in conjunction with other quadcopters to form an intelligent swarm platform.

Despite their notorious reputation, wildfires can be good for plant life and vegetation. It is not unusual for forest officials to conduct prescribed fires meant to reduce low growing local plants, such as palmettos, which are easily ignitable and can spread a fires quickly. However, the real problem occurs when a wildfire becomes uncontrolled. An uncontrolled wildfire can utterly decimate protected areas, wildlife population, and nearby homes. According to National Interagency Fire Center, in 2015 there were 10,125,149 acres burned by wildfires in the United States, this was a record shattering number [1]. In that same year, just in Florida, there were 2422 wildfires reported burning a total of 73,432 acres [2]. This causes unmeasurable damage to protected ecosystems and property, and carries an immense economic burden. In 2015 the total cost of suppressing the wildfires in the United States was $2,130,543,000 [3]. Forest officials and firefighters have the difficult task of containing large wildfires in the varying outdoor conditions. This is a task where we should enlist our most advanced technology to help our first responders, protect lands, and save lives.

1.1 Related Work
There have been some attempts to use quadcopter or drones to tackle this difficult problem in the past. These attempts have had mixed success but lack the advantage of using a dedicated swarm platform to increase effectiveness and reduce cost.

In 2015 Lockheed Martin used two UAV’s, a K-Max helicopter and the smaller Stalker XE in conjunction with a UVA traffic management system (UTM) to extinguish fires. It worked through an elegantly created web of communication, the small UAV Stalker XE would identify hot spots and fire intensity with its electro-optical, infrared cameras. It would then provide the precise geolocation to the larger UAV K-Max helicopter that carried the water payload to that marked location to extinguish the fires, all the while the UTM is tracking the operations and communicating with air traffic control in real time. K-Max helicopter and Stalker XE can both operate day or night with their array of sensors, and durable battery lives. However, despite having been successfully tested, the cost of incorporating and maintaining advanced equipment like this would be too steep for officials to invest in [4].
There was a project related to this topic carried out at Florida International University (FIU) by two undergraduate teams from the mechanical engineering department. They proposed constructing quadcopters that contained a claw like hand that could carry and drop extinguishing grenades on small fires [5]. The focus of their project was on the carrying mechanism, the claw.

There was a similar effort made at the Department of Science and Technology in Hirosaki University. In 2015, they proposed using a similar extinguishing grenade that contained an inert gas, helium. They were able to demonstrate the extinguishment of a small methane fires using a 5L helium “grenade” [6].

2. DESIGN COMPONENTS

2.1 Extinguishing Grenade
For the extinguishable grenade we will be using the Elide Fire Ball Extinguishing Grenade. The grenade is incredibly light at 1.3 kg +/- 5%. One grenade has an operational effective radius of 1.296 meters. The grenade activates about 3 seconds after initial exposure to the flames. The outward force caused by the activation of the grenade causes is not powerful enough to harm humans or the environment. Unlike traditional extinguisher that use Halon, the Elide contains a powder mixture that does not cut off the oxygen supply to the area, this makes it safer to any surrounding or trapped wildlife. Wildfires are generally classified as a type 1A fire which the Elide extinguishing grenade has been rated to extinguish [7].

2.2 Quadcopter Frame
We will use the QAV500 V2 as the customizable frame for our quadcopters. The 540 mm arm frame supports up to 12 in propellers and has an easy install for first person view (FPV) camera needed for leader operation control. This frame also contains carbon fiber on its frame to provide superior strength and stiffness, which is needed for larger arms.

2.3 Control System
The leader quadcopter will be controlled by the powerful and affordable Turnigy 9X RC transmitter. This controller allows for 9 different profiles which could be useful if you have to take over control an autonomous follower quadcopter. In addition, the quadcopters will have the HobbyKing Quadcopter control board. This control board is used to stabilize the UAV in flight. Stabilization occurs by taking in the signal of three onboard gyroscopes (roll, pitch, and yaw) passing them through a microcontroller that processes the signals and translates them via the software installed passing the signals to the Electronic Speed Controllers (ESCs) that makes the fine adjustments to the quadcopter motors rotational speed. The control board will also take signals from the remote controller and make similar adjustments depending on the desired movement.
2.4 Motors
The motors we will need will be the 4108-480KV Turnigy Multistar 22 pole brushless multirotor with extra-long leads. There will be four of these mounted at the end of each arm. Considering we expect the quadcopter to carry a heavier payload and we do not need it to maneuver too quickly, we would need propellers that are at least 12 inches in length.

2.5 Sensors
The quadcopter will be equipped with 4 ultrasonic sensors for collision avoidance as well as leader-follower behavior. The XL-MaxSonar – WR from MaxBotix provides short and long distance detection and ranging. These sensors are rated for outdoor use, are weather resistant, have noise rejection, and auto calibrate.

The brain controlling all the subsystems is PIXHAWK microcontroller and its accompanying accessories. Designed by PX4 Autopilot and 3D Robotics, this microcontroller is one of most popular in the market today. The PIXHAWK microcontroller by PX4 and 3DR is shown in Figure 8.

2.6 Cameras
The primary first person view (FPV) camera which will be attached on top front face side of the leader quadcopter. The camera chosen is Mobius ActionCam 1080P Video Camera. This camera has live video out, which is critical for the leader quadcopter which is be navigated manually. This camera has adjustable resolution and frame rates, and is very light. A picture of the camera can be seen in Figure 9.

The formula that converts given conditions to altitude is seen below

\[ H = 221.152 \times T_{ma} \log \left( \frac{P_0}{P} \right) - H_0 \]  

where

- \( H \) is the altitude in feet above sea level
- \( T_{ma} \) is the mean temperature (in degrees Centigrade absolute)
- \( P_0 \) is the pressure at ground
- \( P \) is the pressure at altitude \( H \)
- \( H_0 \) is the altitude of the ground over sea level

In addition, we will need a GPS flight control system, specifically the 3DR GPS. We will use this data to keep track of movement and as an insurance policy in case a quadcopter goes missing in the field. The GPS will be able to transmit its location data to and from the control systems on the quadcopter.
By far the most expensive piece of technology onboard the quadcopters is the thermal camera. The thermal camera is intended to be placed underneath the quadcopter facing down to identify fires directly underneath.

Thermal cameras range from 1000 – 3000 dollars per unit. Considering our needs do not require high resolution imaging, we can use the Tau2 168 which is one of the more affordable options available from FLIR, a leading company in thermal imaging.

2.7 Power Supply

For a battery pack, ideally we would want to get as much flight time as possible, 15-20 minutes of flight time would be ideal considering the need to reload the payload after each drop.

The Zippy FlightMax 5000mAh 3S1P 20C was chosen because it’s capacity and relative lightweight.

3. PROTOTYPE ALGORITHM

To ensure we minimize the risk of losing any quadcopter equipment out in the hostile field, we will implement a leader follower algorithm. The leader quadcopter will be controlled by an operator on the ground who will be able to see the leader’s video and infrared feed. The quadcopters will use local communication to share information with each other.

The four surrounding ultrasound sensors will determine the correction necessary for the quadcopter to continue follow the leader. Figure 3 shows a depiction of how the quadcopters would be able to detect and correct their orientation based on the ultrasonic signal received.

3.1 Leader Algorithm

In the leader-follower algorithm, the leader will be operated manually by an operator on the field. Figure 4 demonstrates the process flowchart the operator should perform. We would begin by turning on all three quadcopters.

The operator would begin to elevate the leader quadcopter until they reach the desired altitude and it will hover at this altitude. At this point the leader publishes its barometer readings and GPS location to the followers. Once the followers reach the altitude of the leader, the operator should proceed to the target fire.

The operator should navigate using the visual feed from the onboard camera of the leader. Once the leader is hovering over the target, visualized by the underneath infrared camera, it will publish the fire signal to the followers.

At this point the leader will release its extinguishing payload and check if the followers still have their payloads. If a follower still has their payload the operator will move to another target area where a follower could perform the drop.

Once all quadcopters have dropped their payload, an end operation signal is sent to all followers and the operator navigates the leader back to home.
3.2 Follower Algorithm

The follower quadcopters will work autonomously, following the leader while checking several decision operations to determine when their task is complete. Followers are turned on at the same time as the leader and immediately will get the leaders barometric and GPS data.

They will elevate and/or descend until their altitude matches that of the leader. They will then proceed to follow the leader until they receive the fire signal from the leader. At this point they will check if they are hovering over a fire using their underneath infrared cameras.

If they are over a fire they will drop their extinguishing grenade and publish the no payload signal to the leader. Otherwise the follower will follow the leader until it detects a fire underneath it to extinguish.

Once all followers have dropped their payload, the leader will publish the end operation signal and followers will follow the leader back to home.

4. PART LIST

Table 1. Prototype part list

<table>
<thead>
<tr>
<th>Part</th>
<th>Number of Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elide Fire Ball Extinguisher</td>
<td>1</td>
</tr>
<tr>
<td>QAV500 V2 Frame</td>
<td>1</td>
</tr>
<tr>
<td>12 inch Propellers</td>
<td>4</td>
</tr>
<tr>
<td>Turnigy 9X RC Transmitter</td>
<td>1</td>
</tr>
<tr>
<td>HobbyKing Quadcopter Control Board</td>
<td>1</td>
</tr>
<tr>
<td>480 KV Multistar Motor</td>
<td>4</td>
</tr>
<tr>
<td>XL-MaxSonar – WR</td>
<td>4</td>
</tr>
<tr>
<td>PIXHAWK Microcontroller</td>
<td>1</td>
</tr>
<tr>
<td>PIXHAWK Accessory Pack</td>
<td>1</td>
</tr>
<tr>
<td>3D Robotics GPS</td>
<td>1</td>
</tr>
<tr>
<td>Mobius 1080P Live ActionCam</td>
<td>1</td>
</tr>
<tr>
<td>FLIR Tau2 168 Thermal Camera</td>
<td>1</td>
</tr>
<tr>
<td>Zippy 5000mAh Battery Pack</td>
<td>1</td>
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</tbody>
</table>
5. FUTURE WORK
By studying the current landscape and looking at the future ideas for UAV’s in firefighting applications, we have developed a prototype that could help cover some of the disadvantages of other systems. The ideas proposed in this paper are just the initial building blocks. Future work would involve building the proposed design, testing sensors in desired fire detection application, testing the proposed leader follower algorithm, and making sure the entire proposed system works as intended. Potential ideas that could be explored are a change in design of the claw to hold more than one extinguishing grenade, this would allow the quadcopters suppressing fires in a greater area. We could also consider switching from a quadcopter model to a higher performing 8-arm model. Only a small preliminary survey was done for the ideal substance proposed to be used in extinguishing grenades, more research in this field could be done to determine the most effective yet environmentally safe substance to use. Future extinguishing technology may prove to be an attractive alternative, there have been limited successfully test done with acoustic and electromagnetic fire suppression [9].

6. ACKNOWLEDGMENTS
Our thanks are extended to Professor Sabri Tosunoglu and the Robotics and Automation Laboratory located in the Department of Mechanical and Materials Engineering at FIU for making the resources available to carry out this research project.

7. REFERENCES