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Fighting Wildfires Using UAVs
Using Autonomous Biodegradable Self-sacrificing (ABS) Drones to Combat Large Wildfires with the Assistance of Satellite Imagery

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Introduction and Motivation

Wildfires induce a multitude of detriments to communities, ecosystems, and society. Although they are easily initiated by negligent human actions or through the strike of a lightning bolt, wildfires are often difficult and inefficient to extinguish due to their unpredictable nature, jeopardizing communities and putting lives at risk. With the long-term increase in global temperatures and the projected continuation of this trend, a positive correlation can be observed between increasingly dry environments and their heightened susceptibility to wildfires. There were 7,997 more annual US wildfires in 2022 than there were in 2020 [1]. Consequently, wildfires contribute to climate change as well — in 2021, wildfires alone created 1.76 billion tons of carbon dioxide emissions globally [2].

In 2022, 7.6 million acres of US land were destroyed and burned by wildfires [3]. Millions of dollars of infrastructure are damaged annually in the US, and necessities such as transportation, water supply, and gas services are commonly disrupted by large-scale fires [4]. The abounding number of man-made structures destroyed by wildfires serves to provide insight into the social impacts of wildfires as they lead cities to evacuate and permanently change the functioning of communities [5]. Notably, wildfires prove to be deeply rooted social issues that disproportionately impact low-income communities that are significantly more vulnerable and poorly equipped to respond to wildfires in comparison to socioeconomically secure regions. Immigrant communities, individuals living in rural areas, and low-income neighborhoods often do not have access to the resources needed to pay for insurance or invest in fire safety [6]. As wildfires enforce the cycle of poverty, they additionally contribute to poor living conditions and health failures. Smoke and particle pollution induce asthma attacks, heart attacks, and strokes, among other illnesses related to poor air quality. Firefighters who are working directly on or near danger zones face a 68% increase in the likelihood of being diagnosed with cancer, a leading cause of death due to the chemical substances that they use, the byproducts of the fire, and burning structures containing PPE [7]. Moreover, the detrimental impacts of wildfires are apparent through the elevated rates of post-traumatic symptom disorder (PTSD) and depression symptoms. Preceding the Victorian Black Saturday Bushfires, 20% of the population residing in highly damaged areas had a probable psychological disorder a decade later [8].

In recent years, the US has seen a large increase in wildfires attributed to climate change. One of the most destructive wildfires in the last 10 years is the Camp Fire, which occurred in the region of Northern California's Butte County in 2018. It is known to be the most destructive wildfire in California's history. The cause of the wildfire was later found to be faulty electric transmission lines, and combined with the strong wind present, the fire was driven into developed areas. Most of the fire's destruction occurred within the first 4 hours, spreading 153,336 acres and destroying over 18,000 structures, as well as taking not only civilian lives but firefighter's as well. At its peak, about 5,596 firefighters were deployed to fight the fire and save civilians. This does not include the hundreds working at the station to answer the thousands of calls that were sent. Unfortunately, the fire claimed 85 civilian lives and injured 12 civilians and 5 firefighters. Not only were the firefighters physically affected, there were many whose mental health suffered as well. One firefighter mentioned he had heard a family who had called 911 take their last breath, yet he could not do anything but proceed to answer other calls [9]. All in all, the Camp Fire resulted in the destruction of the towns of Paradise and Concow and the cost of the fire is determined to be $148.5 billion [10]. This wildfire is an example of the many future fires that firefighters will inevitably face.

Many efforts were made to fight against the Camp Fire, one of the most important being airplanes. Airplanes and helicopters are a common way to control wildfires using fire retardants and thus creating controlled conditions where it is safe enough for the firefighters to be deployed. However, there are many inefficiencies when using these vehicles. Such vehicles take time to reach their location, and while it might be perceived as a short amount of time, wildfires have the capability to spread at extreme rates. Using planes also puts the firefighter at risk. In order to combat the fire in an efficient manner, the firefighter will have to be close enough to the fire to accurately drop the fire retardant in the midst of unpredictable atmospheric conditions. The graph to the right shows the amount of flight hours and incidents each year. From 2017-2022, not one year dropped below 7,000 incidents. The usage of these planes is also expensive, a tanker can cost more than $6,000 for every hour it is used [11]. In order to combat the wildfires of the future, the need for better tools that are safer and more cost efficient will rise.

Figure 1. Cal file [12]

Problem Statement

Wildfires devastate interconnected systems, permeating the many aspects of human life—society, the economy, and mental and physical health, to name a few. Additionally, their destructive nature contributes to climate change and puts ecological systems at risk of severe impairment. For instance, although drones have been known for their ability to assist firefighters, some drones have caused deaths and helped the spread of wildfires.

This research paper seeks to offer the best possible strategy for combating wildfires by analyzing the shortcomings of current fire-fighting strategies and integrating new types of UAVs which self-sacrifice themselves to reduce the damage of life-threatening wildfires.

Related Works

Currently, there are various strategies that firefighters use to combat wildfires. Firebreaks and aerial firefighting, along with the use of wildfire sensors, are all common methods used against wildfires. With fires that are spreading over 100,000 acres of land, some of the current methods being used have the ability to temporarily save lives. However, it's important to consider that firefighters put their lives at risk, possibly facing death in order to save others. The usage of these current methods is hampered by their dependency on aerial firefighting which often has a delayed response to wildfires and is incredibly costly.

Firebreaks

One common method of slowing fires is digging out vegetation around the perimeter of the wildfire to create firebreaks. This method aims to deprive the fire of fuel and prevent it from spreading further by creating a line of dead vegetation. Firefighters also apply water or fire retardant manually on the ground. This method is heavily dependent on human factors and fire managers must react quickly to changing conditions [13]. Firefighters often have to go into the midst of the wildfire to begin these operations and travel across dangerous terrain during the process. Additionally, firebreaks are quite expensive and must be well-maintained to reduce costs [14].

Aerial Firefighting

Another method commonly used is aerial firefighting with vehicles like tankers, helicopters, and scooper planes. These vehicles fly over wildfires and drop fire retardants at predetermined locations. However, they are often expensive and difficult to maintain. Scooper airplanes cost the U.S. Forest Service approximately $2.8 million annually to operate and maintain, while large helicopters and fixed-wing air tankers cost more than $7.1 million per year [15]. Given the size of the vehicles, the accuracy of the drops are very low and require many drops to properly accomplish their target.

Use of Wildfire Sensors

In recent years, new sensors have been created to monitor the forest's conditions by being mounted on trees. The Silvanet Wildfire Sensor is designed to detect wildfires within minutes by tracking hydrogen, carbon monoxide, and other gas levels, and operates on solar power to have an estimated life span of 15 years [16]. Despite their early warnings, the device itself is not able to partake in any active wildfire fighting activities and is a passive tool designed for observation only.

Autonomous Biodegradable Self-sacrificing (ABS) Drones

Autonomous Biodegradable Self-sacrificing Drones (ABS) are intended to replace aerial firefighting and reduce the need for firefighters to risk their lives when deploying fire retardant. ABS drones work in fleets relative to the size of wildfires to limit the spread of the fire, and so the ABS drones therefore cannot work individually to contain the wildfire before it destroys communities. These drones will be stored in fire engines so that they can go into action as soon as firefighters arrive at the scene. Another prospective place to put the drones in is fire watch towers so that the drones can immediately respond to wildfires before firefighters arrive to reduce the amount of time the fires can spread. ABS drones “self-sacrifice,” meaning they release fire retardant when they fall, limiting the wildfire’s growth in that area. Thus, ABS drones allow fire retardants to be safely deployed without putting firefighters or crewmembers in danger.

Some key advantages of using drones for aerial firefighting purposes include their precision and cost-effectiveness. As they are smaller and more maneuverable compared to larger manned aircrafts, drones can perform surgical operations, meaning that they can target specific areas with greater accuracy. The cost of production should also be low, as each drone is designed for a single use, which eliminates concerns about potential heat or smoke damage. The concept of mass production applies here, prioritizing quantity over quality, thereby enabling the formation of drone swarms for efficient and large-scale firefighting. Instead of investing heavily in the drone's build quality, funds can be more effectively allocated to enhance the capacity of retardant each drone can carry.

A small airplane can carry about 800 gal of retardants [17], which is about 6,676 lbs of retardants, so if each drone can carry about 500 lbs [18] of payload: $\frac{6676}{500} \approx 13.352$, only about 14 drones will be needed to replace a small aircraft.

These drones will be equipped with sensors that allow them to avoid obstacles and navigate safely. They can also be equipped with thermal imaging cameras, which allow them to see through smoke and darkness, making them ideal for firefighting in low-visibility conditions.

In addition, thermal sensors can be useful for detecting when the drone is in dangerous conditions and needs to fall into the fire and deploy their retardant. The environmental impact of ABS drones when they crash into the ground will be discussed in the next section.

The proposed concept integrates the unique aspect of self-sacrificing drones, specifically designed and fabricated with single-use missions in mind. This manufacturing approach will expedite the production process and reduce costs as the drones will not require the integration of expensive payload release mechanisms.

These drones offer an added advantage, namely, enhanced accuracy. Obstacles such as trees, power lines, or buildings force CalFire's aircrafts to fly significantly higher, substantially reducing their drop accuracy and prolonging the time needed to reach the fire site. However, ABS Drones are nimble enough to maneuver between most of these obstacles. This capability allows them to deliver their payload at much more precise locations than larger manned aircraft without putting pilots and crews in danger.

At the end of this section is a storyboard showing how the drones would work. It shows how 1: a fire has been detected in some hills and a firetruck has arrived at the scene with ABS Drones attached to it. Then, 2: the drones are activated and take off from the firetruck, each with a payload of retardants. After that, 3: the drones will either encircle the fire or cover a large section of the fire (if it is too big) and prepare to drop. When they have gotten into position, 4: the drones crash into the ground, deploying their fire retardant in the process. Finally, 5: this can be repeated as many times as necessary until the fire is surrounded (which is the case shown in the illustration) or CalFire's air tankers arrive.

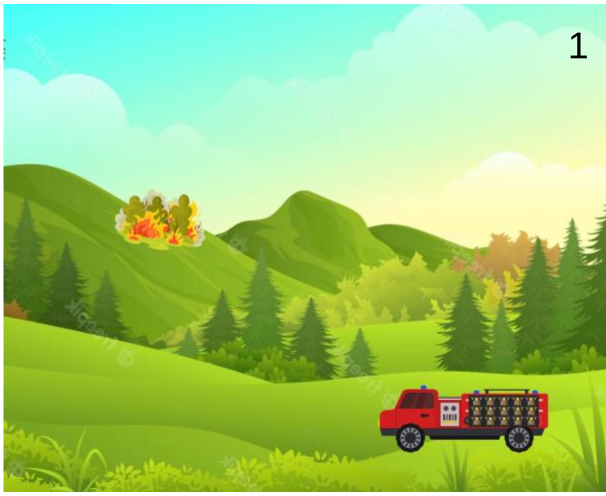
In order to gain further insight into the feasibility of the proposed idea, Brian Centoni, a firefighter captain who is also a drone specialist in a local fire department was able to provide valuable information regarding how this idea could be implemented as well as his thoughts on its potential benefits.

Captain Centoni was very receptive to the idea and believed it could be a valuable tool for fighting wildfires. He noted that CalFire, which operates the large airplanes that deploy retardants, typically takes 15 minutes to arrive on the scene of a fire. This can be a significant amount of time, as wildfires can travel up to 14 miles per hour [19]. Captain Centoni believed that if drones could respond to fires before the planes arrive, they could significantly reduce the size and damage caused by the fire.

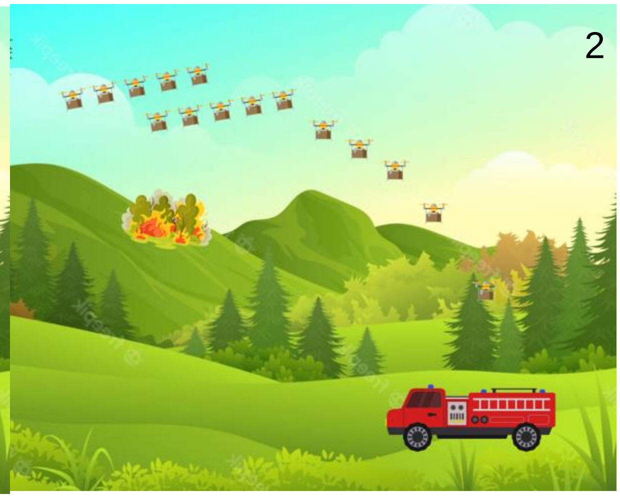
Captain Centoni also noted that drones would not necessarily have to be responsible for deploying all of the retardant. In many cases, they could be used to simply start the process of deploying retardant, which would often be enough to keep the fire at bay until the planes arrive.

Overall, Captain Centoni was very positive about the proposed idea and believed that it could be a valuable tool for fighting wildfires.

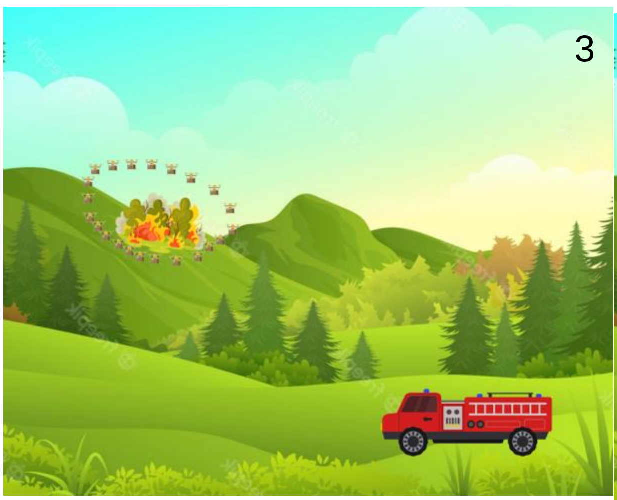
Drones are a relatively new technology, but they have already proven to be a valuable asset for firefighting. The deployment of these drones will yield substantial cost savings in terms of both retardant and fuel due to the efficiency of which the drones operate. In addition, what sets drones apart is their ability to get to the target location significantly faster than other larger aircraft. Otherwise, this valuable time would be expended in conducting multiple runs over the target area to ensure the effective creation of a firewall with the retardant. Therefore, the introduction of these self-sacrificing drones signifies a practical and cost-effective solution for firefighting operations.



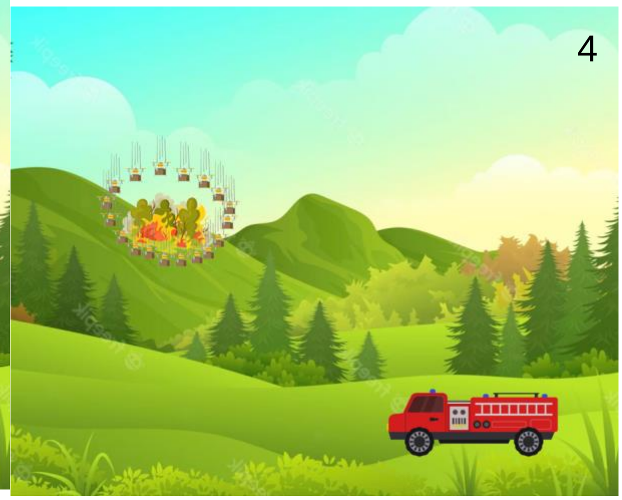
Fire engine carrying ABS Drones arrives at wildfire.



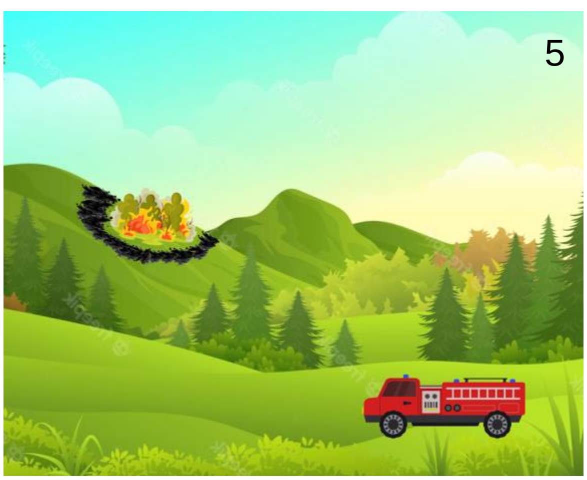
Pre-Programmed Drones released with retardants.



Drones encircle fire (or cover a section of the fire if it is too big)



Drones crash around the fire to deploy retardants.



This is repeated as many times as necessary until the fire is surrounded or CalFire’s air tankers arrive.

Batteries and Biodegradability

The batteries of the ABS drone are an important factor to consider as it must fulfill the conditions of being non flammable and safe for the environment. The best suited battery for this job are aqueous lithium-ion batteries, which are a type of water-based battery made with a fluid electrolyte. Traditional lithium-ion batteries, on the other hand, use a flammable electrolyte, which can cause issues when the drone is in contact with fire. With aqueous batteries, drones that fall to the ground do not explode or catch fire and are also environmentally friendly, lacking toxic chemicals or metals. While not as efficient as the traditional lithium ion batteries with electrodes, these batteries will be sufficient for ABS drones, as they will only be used for a short duration and distance. The aqueous lithium-ion Batteries only go up to 4V, but most consumer drones only need up to 3.8V.

Another important aspect of the drone itself is its biodegradability. It is crucial for the drone to be as biodegradable as possible so it is able to safely fall into the fire while leaving behind minimal amounts of non-degradable substances like wires and the batteries. However, not only does it have to be safe for the environment, it must not fuel the fire further and has to be able to support the weight of the drones and the fire retardant. A substance that is worth looking into is mycelium, which in its basic sense, is fungal threads. Mycelium has been recently used in packaging, architecture and textile, and is known to be 100% biodegradable. It can also be sustainably farmed through using agricultural waste without requiring energy such as electricity and then poured into the molds as needed. When exposed to fire, mycelium is able to create a thermal protective char layer which makes it fireproof. Thus mycelium can act as a fire retardant substance, making it safe for the drone to be able to drop down without the risk of potentially fueling the fire further [20]. However, while its strength to weight ratio is stronger than that of concrete, a disadvantage of using mycelium is that it will not be able to support more than the basic drone structure itself. As NASA has done before, it is possible to create a mycelium drone built for the sole purpose of flying. However, with the added weight of the retardant, which is proposed to be roughly 500 pounds, it is insufficient. As of right now, the best usage of mycelium will be in the fire retardant itself to ensure the retardant is less toxic to the environment when used. It is also important to continue researching mycelium and creating a similar substance to see if it will have the capability to carry a large amount of weight while ensuring it will be completely biodegradable.

Satellite Technology

Satellites have been traditionally used in combination with drones for communication in war. This normally includes both a communication satellite and a GPS satellite. The communication station is meant for the pilot to be able to communicate with the UAV and guide it to its needed place. When the connection is lost, it is then connected to the GPS satellite to autonomously return to its designated spot as programmed. This technology only has to be slightly modified to make it suitable for the ABS drones.

Satellites can be used to map large areas of land and guide drones to their target location as wildfires burn. Integrating satellite data and drone technology will allow for real-time adjustments to be made as fires quickly spread, and satellite guidance can grant autonomy to the drones, allowing for efforts to be diverted elsewhere when combating wildfires. Using satellite data of fires spreading could allow drones to quickly adapt to the wildfires' unpredictable nature.

Additionally, these satellites could serve the purpose of detecting factors that contribute to fires preemptively—temperature, precipitation, and soil moisture. Any anomalies that are detected at drastic levels may prompt the dispersion of drones towards the site which work as the first response or help in the preparation of combating a potential wildfire. One example is using existing satellites, such as NASA's Soil Moisture Active Passive (SMAP) [21] to detect and measure the water content of surface soil around the world, which are used in predicting the possibilities of natural disasters. Through a satellite designed specifically to measure the warning signs of fires, we can place drones at a hazardous location before the fire even starts, possibly preventing the destruction of communities and acres of land.

Costs

The major cost associated with any electric device or vehicle, such as a firefighting drone, predominantly lies in the battery. These high-capacity power sources are essential for providing the necessary energy to operate the device efficiently. However, they often come at a significant price. For instance, a typical firefighting drone is estimated to cost around $10,000 per unit, primarily due to the expenses incurred in acquiring and incorporating a suitable battery [22]. In addition to the initial purchase cost, there are further long-term expenses to consider, such as maintenance and upkeep. Just like any complex machinery, firefighting drones require regular maintenance to ensure optimal performance to extend their operational lifespan. This includes periodic battery replacements, system upgrades, software updates, and general repairs. These ongoing maintenance costs can accumulate over time, further adding to the overall expenditure associated with the drone. However, there is room for significant cost reduction by exploring alternative materials and implementing innovative design solutions, as proposed in recent studies and technological advancements. Researchers and engineers have been actively working towards finding ways to make drones cheaper, with one such way through the use of biodegradable materials and water-based lithium-ion batteries. Agricultural drones that can fly up to 900 acres and for an hour typically have battery sizes of around 100,000 mAh, with prices ranging around $1000 [23]. However, water-based lithium-ion batteries in this project are projected to be around half of the cost of current lithium-ion batteries at the same capacity [24]. This is because — unlike organic solvents used in conventional Li-ion batteries, which can be costly to acquire and process — water is abundant and easily accessible. This inherent affordability of water contributes to the overall reduction in battery production costs. Manufacturers can benefit from lower material expenses, resulting in more cost-effective battery packs for drones.

Conclusion and Future Works

Wildfires are a major issue that perpetuate the cycle of poverty and make it difficult for people to escape it. As a wildfire progresses, it destroys not only a person's possessions and livelihood, but also the stability that firefighters and other community members have worked hard to build. This can lead to a cycle of poverty that is difficult to break. The solution to this problem is to control wildfires and extinguish them quickly. While the answer is simple, the actions and methods are complex.

This paper proposes a solution that is just the beginning of a new future. Using ABS drones to fight large-scale fires will not only benefit the firefighting community today, but also represent the future of firefighting. This could mean that drones will replace fire engines or even prevent fires from starting in the first place. However, this research cannot stop anytime soon. As climate change progresses and global warming increases, there will be many vulnerable places that need protection that human forces today may not be able to provide. With advancing technology and the increased use of AI in everyday tasks, humans will soon not be involved in dangerous jobs like firefighting. Instead, the future holds endless possibilities for drones to carry out the entire job of putting out a fire, from start to finish.

Although this future is still far away, with the progression of technology, technological vision is becoming a reality faster than ever before.

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