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UAV Path Planning for Wildfires

Sustainably Fighting Wildfires with Automated Path Planning for UAVs

** All authors contributed equally to this memo. The names are listed alphabetically by surname.*

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Table of Contents

Abstract

As the severity and frequency of wildfires increase, infrastructure, properties, national parks, animal habitats, and human lives (civilians and firefighters) are put at greater risk. This paper examines the possible application of algorithmic path planning for UAV reconnaissance to reduce damage and safety risks, as aforementioned. When the location of a wildfire is known, UAVs are immediately dispatched from an operating base to fly to the fire and support the firefighters as quickly as possible. Then, the algorithm incrementally analyzes different environmental factors to create a path for the UAV to follow. This work focuses on generating a path for the UAV to follow given a set of polygons representing obstacles. The most important features of this algorithm are its fast response time and obstacle maneuverability. The use of an efficient path planning algorithm could potentially save lives, infrastructure, and acres of forest destruction.

1 Introduction

Wildfires have become an increasingly threatening problem in the last decades. The United States has experienced a 223% increase in wildfires since 1983, and a 19% increase in wildfires since 2019. Furthermore, California has experienced great losses as a result of increasing wildfires, being ranked first in the US for the most fires and acres burned, and having the highest wildfire risk. In 2021 alone, California witnessed 9,260 fires and more than 2.2 million acres of land burned (Insurance Information Institute, n.d.). Wildfires are detrimental to many aspects of life. Wildfires release carbon emissions which contribute to climate change and the greenhouse gas effect. In 2020, California released more than 91 metric tons of CO_2 from wildfires. Severe and frequent man-made wildfires also damage ecosystems, causing a loss of habitat and resources for wildlife and vegetation (Buis, 2021). Wildfires have also put the lives and properties of millions of people at risk. In California during 2021, the properties of more than 2 million people were put at wildfire risk (Insurance Information Institute, n.d.). Wildfires prove a risk to human health as wildfire pollution can reduce lung function and cause heart failure, bronchitis, and a span of other health disorders (Environmental Protection Agency, 2022). Wildfires have simultaneously resulted in large costs for suppressing fires alone. In the last 5 years, the average annual federal firefighting cost was more than 2 billion per year (National Interagency Fire Center, n.d.).

Current firefighting efforts involve several teams such as a command team, firefighting crew, etc. arriving at the location of fire after detection. The Incident Commander (IC) then observes the fire's behavior, terrain, and other aspects to develop and deploy a strategy for suppressing the fire (Environment and Natural Resources, n.d.). However, an IC's knowledge of the fire at hand can be limited when there is no real-time data and details of the fire at hand, especially in hard-to-reach landscapes. This is why Unmanned Aerial Vehicles (UAVs), or drones, have started to gain popularity in support of wildfire management over the last few years. In 2019, the number of drone flights executed by the U.S Department of Interior and other wildfire agencies increased to 2,389 flights (Adorama, 2022). The amount of drone flights across fire departments in the U.S has also increased due to new legislation. In March 2019, the Wildfire Management Technology Act was passed into law, which authorized the use of drones/UAVs and further spread their usage (CRS, 2018). UAVs are able to fly in complex terrains and weather which manned aerial/ground vehicles would have greater difficulty in navigating, alongside a greater risk to the life of the firefighter. UAVs provide reconnaissance through their high precision cameras and thermal sensors, which inform firefighters of details about the fire, such as the fire's boundaries, locations, and hotspots.

Drones are being used to assist in wildfire extinguishing. Alongside its gradual implementation in fire departments, NASA's Scalable Traffic Management for Emergency Response Operations (STEReO) project, led by Joey Mercer, is utilizing drones for faster, smarter, and safer emergency response operations (Tabor, 2021). In 2021, the STEReO team participated in wildfire response operations in Northern California, where they manually launched drones that informed firefighters of fire trends and characteristics (Tabor, 2021). The drones helped firefighters confidently assess the situation and make quick decisions. In an interview with Mercer, he described current drone operations as being "super manual…they [UAVs] rarely even go into waypoint mode. It's so manual, they always have to take safety into consideration, and the dynamic environment or situation into consideration…" By implementing a path planning algorithm for UAVs, the manual aspect of controlling the UAV to get to the fire or a specific point would become significantly more efficient. Because the UAV calculates the fastest and most efficient route, it will allow firefighters to reach the point of fire quicker. Thus, this saves time in navigation, reconnaissance, and the relay of important time-sensitive wildfire data. In addition, firefighters would be able to prevent the fire from spreading more quickly, which would mitigate and reduce the harmful impacts of wildfires as described above.

In this paper, we propose a path planning algorithm that takes into account aircraft, terrain, static and non-static obstacles, and weather/situational data in order for a UAV to get from a point A to point B as fast as possible. The rest of this paper goes on to describe the factors considered for the software development, the steps taken to implement the search algorithm, and finally, the conclusions made from the study as a whole.

2 Approach

To address our research question, we concluded that automating the process of path planning for UAVs could potentially reduce the current severe impact of wildfires. To start, we will define path planning: Path planning is the process of finding a geometric route to a target location considering various factors (Montazeri et al., 2021). Path planning is essential for firefighters to put out fires quickly and efficiently (Chou et al., 2019). Our approach is to create software that can automate this process.

We are considering several parameters as inputs for the program. The specifics of why we chose these factors to consider will be discussed later in the paper—but some examples include specific coordinates of the starting point and any point from the region of the fire, the wind speed/direction, the time of day, terrain, fire resistance, etc. These parameters are analyzed to create an efficient route for UAVs to follow to reach the fire quickly and sustainably. This allows for reaching the fire faster and thus minimizing the fire's devastating impacts. The specific algorithm we use will be discussed in further detail in the Algorithm section of the paper.

2.1 Software Components

Figure 1 illustrates crucial components that are used to create an optimized route for the aircraft vehicle. If available, the data for outgoing flights will be used to gain a better understanding of the potential obstacles which is provided by the System Wide Information Management (SWIM) or more specifically, the Integrated Terminal Weather System (ITWS). Static data such as geographic obstacles will also be analyzed so that the aerial vehicle may avoid them. Currently aircraft vehicles are manually operated, and the Graphical User Interface (GUI) is the primary way of communication that the IC uses to guide the aircraft. Depending on the type of vehicle used, there might be a pilot onboard that requests a replan of the route as well as providing more data about the current surrounding environment.

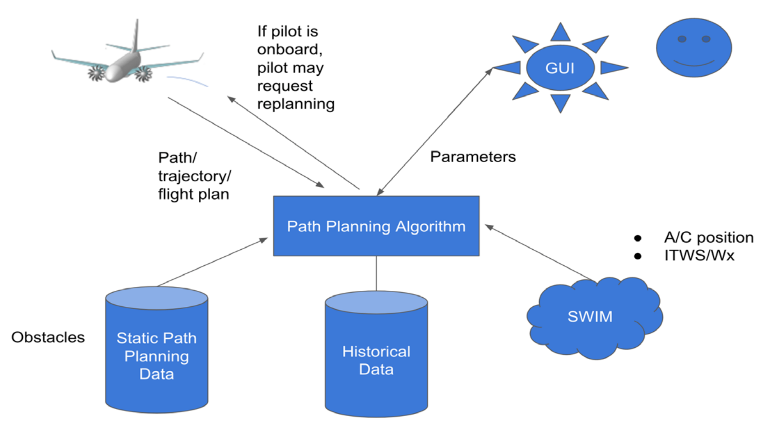

Figure 1. High-Level Software Architecture

The possible environmental obstacles and types of aerial vehicles used to deploy the task are taken into account in the software. Weather and topography are such obstacles that impact wildfire behavior which in turn affects the generated pathway for the aircraft. For example, wind "can bring a fresh supply of oxygen to the fire and push the fire toward a new fuel source" (National Park Service, 2017). This increases the rate at which it spreads as well as the distance between the vehicle and the fire. The software would generate an optimized pathway to account for these changes.

High temperatures may also dehydrate land leading to an increased chance of ignition in the area. Fires have become more common in the spring and summer seasons, burning about 0.4 million acres of land to 1.2 million acres (EPA "Climate Change Indicators: Wildfires", n.d.). Some topographic characteristics considered are elevation, slope, and slope direction (National Park Service, n.d.). Terrains such as canyons, valleys, trees, hills, and mountains "can affect localized wildfire behavior by funneling wind and increasing their speed, helping rapidly spread fires" (Sistek, 2021). These terrains might impact the process of generating a pathway by requiring more precise maneuvering to reach the target location. Because lower elevations are warmer in temperature, the fuel would be susceptible to catching on fire as illustrated in Figure 2. Slopes, depending on the direction, can spread fires more quickly "because it can pre-heat the upcoming fuels with rising hot air, and upward drafts are more likely to create spot fires" (National Park Service, n.d.).

Another factor to assess is the different types of wildfires such as urban or forest fires that influence the speed at which a fire spreads. The type of fire would also provide information about whether it is likely that multiple fires would arise or would maintain a single fire. The software would identify high-density areas to contain and build a pathway to account for the speed of the fire as well as possible topographical obstacles the aircraft might encounter.

The type of aircraft vehicle also influences the optimal route to the fire. Some vehicles may be capable of navigating through complex/ intricate obstacles such as a UAV whereas airplanes and helicopters may not. The pathway created would have to accommodate this so that the vehicle can still reach and contain the targeted location. Each vehicle also has limitations on what resources it could carry including water, retardant, and the use of firefighters. A UAV would not require a firefighter inside the aircraft but have "a payload of upwards of 500 pounds" (Malczan, 2021). On the other hand, helicopters can "carry water in buckets that hold between 100-400 gallons of water" (US Forest Service, "Helicopters") whereas airplanes can carry anywhere from 800-8,000 gallons of fire retardant (US Forest Service, "Planes"). Helicopters can hover whereas airplanes can fly long distances. The fire tolerances of each vehicle type vary which is critical because it determines how close the aircraft can hover over the fire. A UAV may be less tolerant to fires, flames, or heat than an airplane or helicopter. Overall, these factors are taken into consideration as they would increase or decrease the distance to the fire and the amount of time needed to arrive at the targeted location.

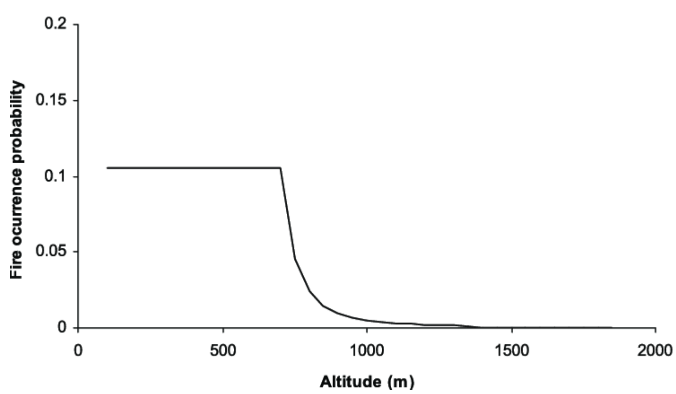

Figure 2. Altitude Effect on the Probability of Fire

2.2 Algorithm

Taking into account potential factors such as terrain and other obstacles, a search algorithm is able to find a cost-effective route for any given starting and ending point. This can be applied to wildfire scenarios, where UAVs can be given the fastest route between points A and B (while also avoiding potential obstacles specific to wildfires, such as terrain) to provide vital firefighting support. For the algorithm's input, each obstacle is represented by a convex polygon, and each polygon is composed of a set of points, ordered counterclockwise. The obstacles can represent possible factors present in the environment, such as terrain, topography, or temperature. This work focuses not on how to represent specific obstacles as polygons, but on the path search problem given a set of polygons representing obstacles. Below, the steps to implement this search algorithm are described in detail.

2.2.1 Search Map Buildup

Before a search algorithm can be implemented, it must first have a search space, as well as an obstacle map. The starting and ending points, as well as obstacle coordinates, must be designated beforehand. Using quadtree decomposition, a framework is set for the areas the algorithm will search. Quadtree decomposition works by "dividing a square image into four equal-sized blocks, and then testing each block to see if it meets some criterion of homogeneity" (Mathworks, n.d.). For the specific wildfire path-planning problem mentioned above, quadtree decomposition [1, 2] sorts nodes into three categories: empty, mixed, and full. Empty cells have no obstacles present inside, full cells are completely contained by an obstacle, and mixed cells intersect with an obstacle but are not fully contained. Quadtree decomposition splits parent nodes into four children nodes if they meet the criteria of being mixed. Otherwise, the cells are not split. This process is repeated until a designated depth level. The depth level can be adjusted depending on the buffer distance needed from the obstacles, which may be different depending on the aircraft navigation and tracking performance. Below, Figure 3 shows quadtree decomposition for a sample obstacle map at depth level 8.

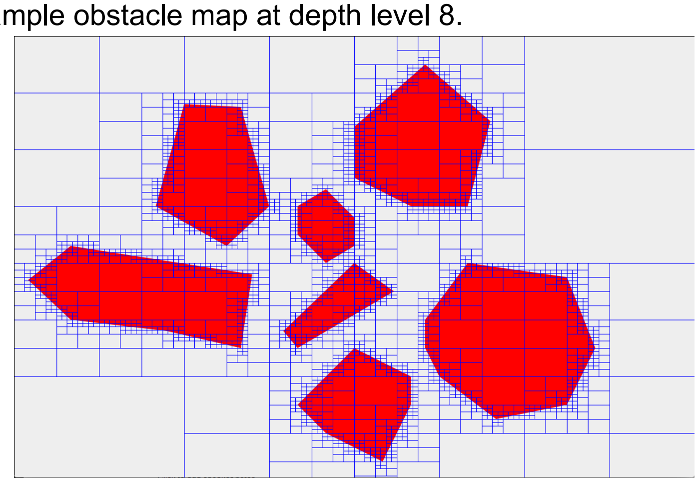

Figure 3. Quadtree Decomposition at Depth Level 8

2.2.2 Search Algorithm

Finally, a search algorithm can be implemented to find the shortest route between two points. From the starting node, the algorithm searches adjacent nodes and picks a node based on a value f [2]. The value of f is the sum of two parameters g and h; g is the cost, or distance, from the starting node to the adjacent node, whereas h is the heuristic cost. The heuristic cost is the estimated distance from the adjacent node to the ending point; it is a straight line that ignores any potential obstacles. The purpose of the heuristic cost is to improve the efficiency of the algorithm by ensuring that the chosen path is in the correct general direction. At each node, the algorithm picks the adjacent node with the smallest f as the next node in the path. The search algorithm repeats this process until an optimal path between the two points is constructed. Figure 4 shows a final path for a sample obstacle scenario generated by the algorithm.

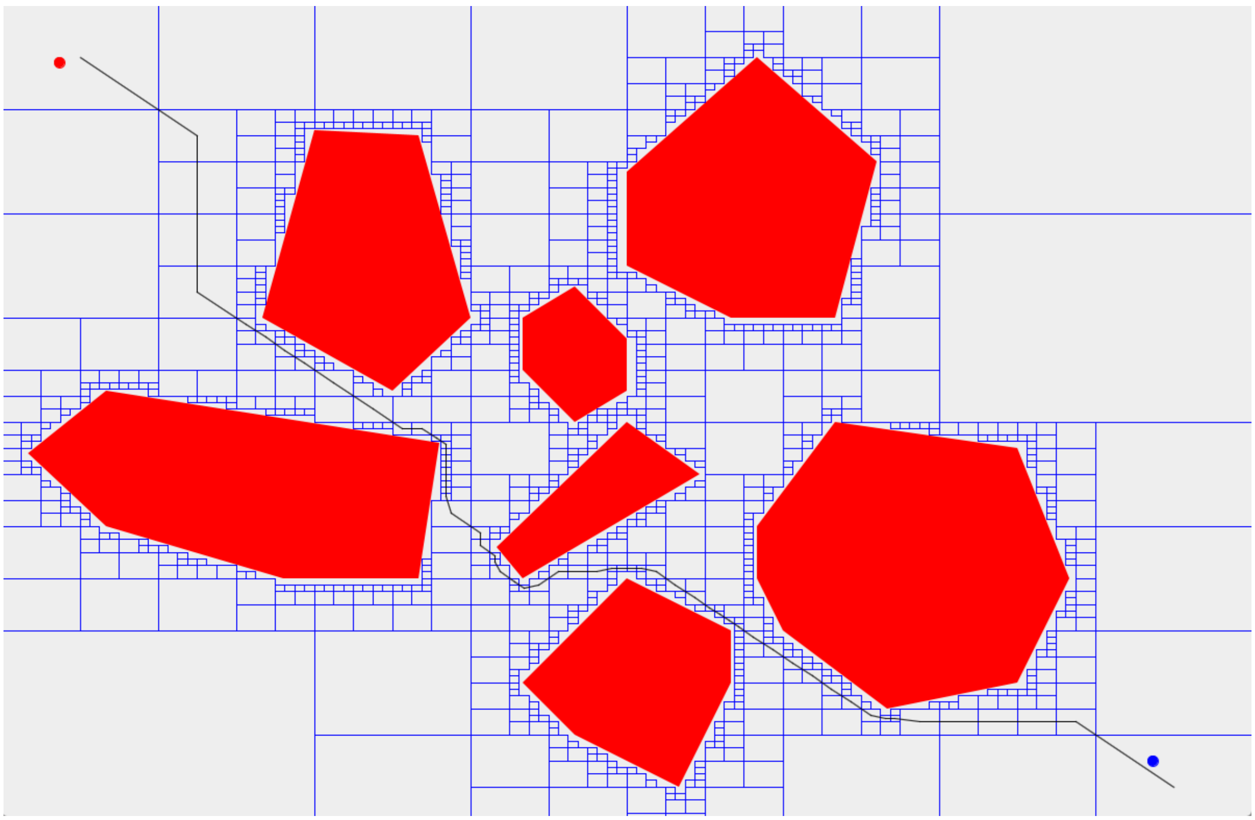

Figure 4. A Final Path Generated by A Search Algorithm*

Although an A* search algorithm was used in this example, other search algorithms such as Theta* could be used to enlarge the area for "neighboring nodes" to allow more flexible heading angle selections. This would be useful for accommodating performance limitations of specific vehicle types. Generally speaking, this type of search algorithm complexity is O(log(n)), meaning they have great potential to be applied in real-time environments.

3 Conclusions

As wildfires become increasingly prevalent, it is more crucial that fires are efficiently analyzed and extinguished, requiring careful coordination and management of firefighting resources. UAVs supplement firefighting by providing an additional and essential vector of support, allowing for logistical tasks such as reconnaissance and communications to be deployed with less human intervention. Unlike manual piloting, UAVs have the added benefit of having a lower safety risk to humans by removing the pilot from the air; thus, UAVs would be able to prioritize their missions on importance rather than pilot safety.

With automated path planning, UAVs can become fully autonomous, eliminating the need for even a human observer. Path planning generates an efficient path to specified targets, whereas automated path planning software accounts for variables in real-time. Automated Path planning software would look at factors that affect a flight plan, such as the heatmap of a fire and localized weather patterns and make changes in real-time to allow a UAV to efficiently reach its target. Automated Path planning eliminates the need for humans to manually enter flight paths and thus one human could control numerous UAVs. While this work focuses on path planning given a set of obstacle polygons, future work would be necessary in order for this path planning method to be truly autonomous. This future work would include processing environmental data into obstacle polygons in real time, in order to account for and adapt to changing environmental conditions.

Although these new technologies are promising, like all new technologies they require time to progress and mature. In most use cases, technology can slowly progress in three phases, starting from a “crawl”, progressing to a “walk” and speeding up into a “run”. However, in firefighting due to the risk to human lives, new technologies must skip the crawl phase and go directly into a run, requiring testing to be done outside of actual wildfires. Because firefighters are unable to field test fully autonomous UAVs, this adds a psychological component where firefighters may be uncomfortable being on the ground while a newly released UAV is flying overhead in place of an experienced pilot.

Despite these potential setbacks, UAVs have enormous potential in the firefighting industry. UAVs can be specialized to perform specific and complex firefighting functions through physical and software modifications. Software additions such as Automated Path planning will give UAVs a new boost into the field of firefighting and allow for fires to be tackled faster and more efficiently.

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