Aerial Fire Fighting System for Efficient Wildfire Management

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***Abstract* - A wildfire refers to an uncontrolled fire that ignites in a natural environment. Property damage and serious harm to personnel can arise from fire accidents, which often occur suddenly and unexpectedly. When the Fire service responders arrive on a wild fire scene, it is very difficult for them to predict the situation inside the forest subjected to Fire. Efficient Wild Fire Management comprises a systematic approach of fire suppression. Hence Drone can be a solution for the Fire fighters to take decisions about where to concentrate resources and how to approach and enter the scene. In this paper, a novel design for a Firefighting UAV with shooting and dropping mechanism of fire extinguishing ball has been developed and successfully tested. The drone can be controlled by the fire personnel from a safe distance with an accuracy of 93.5%, thus significantly reducing the degree of human involvement and risk of physical injuries in firefighting.**

Key word: Fire Fighting Drone, Wildfire, Fire Extinguisher Ball

I. INTRODUCTION

Forests play several important roles in the natural environment, including purifying water, preventing soil erosion, recycling nutrients, regulating climate, sequestering carbon dioxide, and generating oxygen. They are the habitats for the wildlife, and an important segment of the country's economic wealth. However, every year millions of acres of forest are lost because of forest fires. The forest fires can be divided into two broad classes; wildfires and prescribed fires. Wildfires are either caused by accidental or malicious acts of human or by nature (lightning, etc.). Detecting and extinguishing wildfires promptly is essential due to their rapid spread through convection and prolonged combustion cycle. Unfortunately, intervening early is often hindered by difficult-to-access terrain and the influence of wind, compounded by diverse fuel sources present in forested areas.

A wildfire is simply an uncontrolled fire that is wiping out large fields and areas of land. It often starts with a lightning strike, or people carelessly starting it, or accidentally, or even arson, that went unnoticed and got out of hand. These fires sometimes burn for days and weeks. They can wipe out an entire forest and destroy almost every organic matter in it.

The profound devastation caused by forest wildfires is extensive. Forests encompass entire ecosystems, encompassing living beings such as animals, insects, birds, bacteria, plants, and trees, alongside non-living elements like water, rocks, and the specific climate of the region.

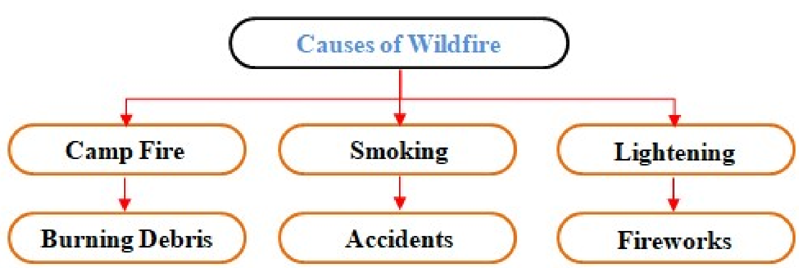

Fig 1: Causes of Wildfire

1.1 Need for Drones in Fire Fighting:

The increasing demand for drones spans across civilian and military sectors, offering diverse functionalities such as search and rescue operations, environmental conservation, delivery services, defense purposes, and exploration in space and marine environments. This project specifically focuses on harnessing drones for firefighting tasks. Swift suppression of forest fires is paramount, considering the significant economic, environmental, and societal impacts they demand. To decrease the fire burden, currently UAVs are used by several fire departments nationwide for search and rescue operations, and for situational awareness assessed by monitoring, detection, diagnosis and prognosis. Over the past decade, scientific studies have explored the utilization of drones in wildfire management from both technical and non-technical viewpoints.

1.2 Types of Drones Used in Wildfire Management:

Firefighting drones come in various types, each designed to serve specific purposes in combating wildfires. Here are some common types of firefighting drones:

a. Water Dispensing Drones:

These drones are equipped with tanks or reservoirs capable of carrying water or fire retardants. They are deployed to drop water or retardant onto active fire zones, helping to suppress flames and create firebreaks. Water dispensing drones can operate autonomously or under remote control, delivering payloads accurately to targeted areas.

b. Foam Sprayer Drone:

These drones have in built storage tank with suitable chemicals controlled by servo motor and spraying gun. These can be utilized when fire is caused by electric short circuit or chemical accidents.

c. Thermal Imaging Drones:

Thermal imaging drones are equipped with infrared cameras capable of detecting heat signatures and hotspots. They provide real-time thermal imagery to firefighting teams, enabling them to identify hidden flames, assess fire behavior, and locate hotspots that may not be visible to the naked eye. Thermal imaging drones help firefighters monitor fire spread and prioritize areas for intervention.

d. Sniffer Drone:

Sniffer Drone equipped with an air monitoring system that collects data on the chemical that are in the air`. It does so by flying to a measuring point, for example through a cloud of smoke, and at the location it measures the presence and the concentration of different chemicals.

e. Aerial Reconnaissance Drones:

Aerial reconnaissance drones are used to conduct surveillance and mapping of wildfire-affected areas. Equipped with high-resolution cameras and sensors, these drones capture detailed aerial imagery and terrain data, allowing firefighting agencies to assess fire extent, monitor fire progression, and plan firefighting strategies. Aerial reconnaissance drones provide valuable situational awareness to incident commanders and support decision-making during wildfire response operations.

g. Communication Relay Drone:

Communication relay drones serve as airborne communication hubs, providing connectivity and network coverage in remote or inaccessible wildfire zones. Equipped with communication equipment, including antennas and repeaters, these drones establish wireless communication links between ground crews, incident command centers, and emergency responders. Communication relay drones facilitate coordination, information sharing, and resource allocation during wildfire response efforts, particularly in areas with limited or disrupted communication infrastructure.

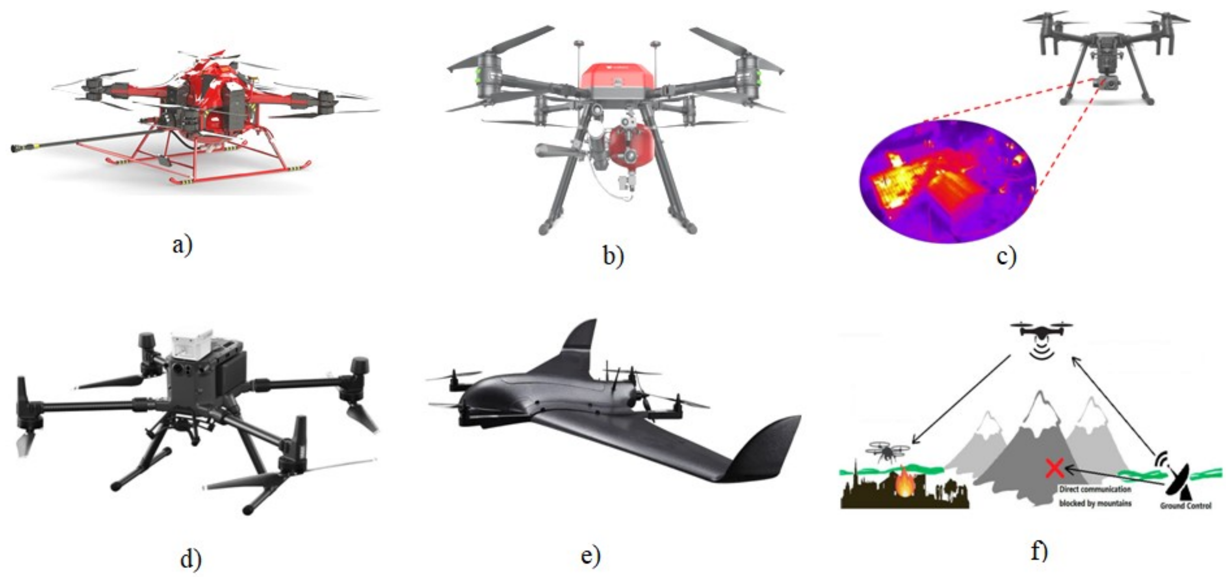

Fig 2: a) Water Dispensing Drone b)Foam Sprayer Drone c) Thermal Imaging Drone d) Sniffer Drone e) Aerial Reconnaissance Drone f) Communication Relay Drone

Challenges encountered during wildfires include rapid spread due to weather conditions like wind and dryness, difficult terrain hindering access for firefighting efforts, limited resources and personnel, communication issues, and the risk of secondary hazards like smoke inhalation and property damage. These difficulties can be overcome by utilization of drones.

II. LITERATURE SURVEY

Abinesh. D. V et al. (2017) designed quadcopter for the purpose of exploring the areas hit by fires. The author compared different configurations of drone and finally selected the quad with arm length of 220 mm, owing to its intuitive simplicity in its manufacturing and cost effectiveness. The propeller used is 10 x 4 inches with the idea of improving stability. The materials of the propeller are chosen keeping in mind the temperature, the drone has to undergo while it is close to the fire. [1]

Dr. Ronald T. et al. (2018) discussed the concept and issues related to the unmanned aerial systems in the fire service. Emphasis is placed on airworthiness of the drone, command and control of the drones and crash avoidance. Recommendations include continued field testing on UASs, surveying fire chiefs to access opinions on UAS implementation, and coordination between the Federal Aviation administration (FAA) and fire chiefs in regulation development on UAS technology use in the fire service [2]

Burchan et al. (2019) demonstrated the use of Drone assisted wildfire fighting using fire extinguishing balls as a supplement to traditional firefighting methods. The proposed system was a hexacopter with a payload weighing 15 kg and balls of weight 0.5kg each. It consists of scouting unmanned aircraft systems (UAS) to detect spot fires and evaluating the risk of wildfire approach to the building. It also sends the relative data of the firefighting UAS to help them to control the situation. However, these balls were not effective for class A & B fires. [3]

Abdulla Al-Kaff et al. (2019) developed autonomous UAV for the critical applications of forest fire surveillance. Algorithms implemented into the device to perform surveillance tasks within a specific area, to perform autonomous take-off/landing, trajectory planning and fire monitoring. This design is equipped with thermal cameras, temperature sensors and communication modules to provide information about the fire and reporting to the Emergency Response Team (ERT). [4]

Saikin, D.A., Baca et.al (2020), stated similar approach based on water spray is followed under outdoor conditions. The novelty of this research is based on its lightweight and low power consumption water collecting/releasing system. [5]

Wang et al. (2020) introduces a novel fire drone extinguishing system for high-rise buildings. The system contains a twin-rotor drone among others high-pressure fire extinguishing equipment. They present different firefighting tactics based on drone and fire truck cooperation and multi-drone cooperation. [6]

Alon, O., Rabinovich et. Al (2021) explored how drones are integrated into firefighting teams. They propose a Human-Drone Interaction methodology based on gestures, where both can communicate directly with each other. [7]

Spurny, V., Pritzl et.al (2021) designed a novel approach to autonomous water spray extinguishing of indoor fires inside a building is presented. The authors also presented a constrained optimal control solution that exploits the variable time mass of the drone. However, the use of water spray as firefighting behavior is very limited to the amount of water that the drone can carry (payload capacity), strongly limiting the extinguishing power of the drone. [8]

III. OBJECTIVES

- To develop an unmanned aerial vehicle which can navigate and fly using hand-held remote control operated by the fire fighting employees from safer distance.
- To deploy a sensor-based system which can detect wildfire when the drone is flying
- To develop a mechanism this can carry fire extinguishing system as a payload of the drone.
- To develop innovative design is to be made for the dropping mechanism of the fire extinguisher ball which is mounted on the drone.
- To deliver the fire extinguisher ball in an area that is difficult to approach by conventional methods.

IV. DESIGN OF FIRE FIGHTING DRONE MODEL:

This section discusses the basic Quadcopter dynamics, as well as control concept. The Quadcopter have four propellers and each is powered with individual electric motor. The entire system is powered by rechargeable batteries, and it can work either in fully autonomous or semi-autonomous mode. The electronic control system to achieve autonomy is already available in the form of Flight Control Board (FCB) which is not expensive and fully evolved. Propeller blades are normally made of composite materials and are also available in various dimensions. To reduce the weight, they are commonly made with carbon fibers. Transceiver and other electronic components are kept in the fuselage which is commonly made up of composites or aluminium materials.

a. Frame:

The frame of the multi-rotor gives it a structure and provides a place where all the components can be attached. Frames are conventionally made up of carbon fibers or hard plastic or aluminum. The materials for frame will be chosen by considering the purpose of the drone, and the frame's importance in keeping the drone stable and allowing the drone to have a smooth flight. Frame contributes 30% to 35% of overall weight of the drones. [9]

b. Release Mechanism:

Fire extinguisher is; loaded to the drone with help of a dropping mechanism fabricated using aluminum. Aluminum is used because its light and easy to fabricate. It also serve purpose shielding the payload and electronic components from the fire, so it is fabricated as a metal box and dropping of the payload is controlled by the servo motor.

c. Thermal Imaging Camera:

The camera DJI Zenmuse XT, provides high-sensitivity about 50 milli Kelvin(mK), thermal imaging at 640/30 Frames Per Second (FPS) or 336/30 FPS. This sensitivity provides accurate temperature measurements ideal for analytics and telemetry. Stabilized and controlled by a custom DJI gimbal, it provides smooth, clear imagery and 360 degrees of seamless rotational movement.

d. Li-Po Battery:

The battery that can be used is a six cell Li-Po battery of 1200 mAh 15c current capacity and 22.2V.

e. Flight Controller:
The flight controller helps in the maneuvering operations and also it provides Auto level function. The accelerometer and gyroscope sensors in the Flight controller process the signals from the receiver and give the output to the ESC. The Pixhawk 1 Flight controller can be used in the Drone

Fig 3: a) Drone Frame b) Release Mechanism c) Thermal Image Camera d) Li-Po Battery
e) Flight Controller f) ESC g) Propeller h) BLDC Motor i) LED Lights

f. ESC:
It stands for Electronic Speed Controller and it is used to vary the RPM of the motor. 80A rated ESC is used as per the motor and battery specifications.

g. Propeller:
The propeller is of 30 inches length and has 10.5 inches pitch. It is made up of carbon fiber and Epoxy and it has less weight. These propellers also have High strength to weight ratio

h. Motor:
Outer runner BLDC motors in which there are no brushes, they have a permanent magnet. The RPM of the motor can be controlled by varying the input current. This motor U12 KV100 produces 4440 maximum Revolutions Per Minute (RPM) with 12s Li-Po battery and it produces a maximum thrust of 13392 grams with 30X10.5 inches propeller
i. Powerful Led Lights:
Light supply is required in the Dark regions and it also helps to obtain bright and clear images through the camera. The Lights system that can be mounted on the Drone is two Lume Cube 1.0 waterproof LED Lights. This light system can be adjustable via 10 manual brightness settings through Bluetooth Wireless Control

V. PROTOCOL OF FIRE FIGHTING DRONE:

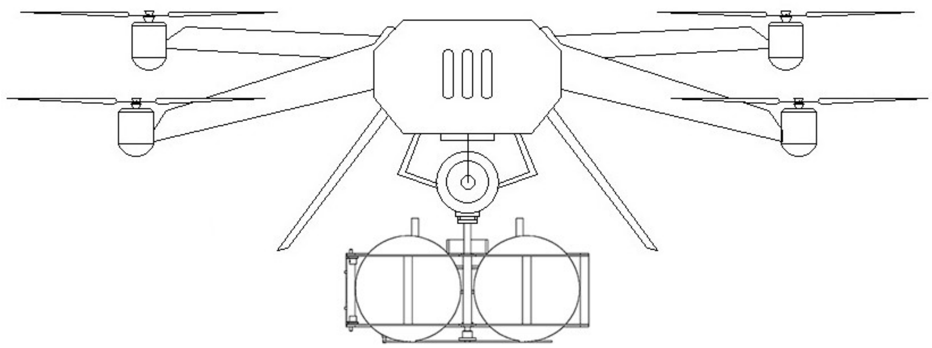

Fig 4: Fire Fighting Drone Model with Ball Extinguisher

After carefully inserting the extinguishing spheres into the dispenser, ensuring their secure placement, the next step is to verify the transmission of the camera mounted on the drone. This is crucial for obtaining real-time visual feedback during the firefighting operation. With the camera successfully transmitting, the drone is powered on, its propellers humming to life.

Once the drone is activated, communication with the dispenser control is swiftly established, ensuring seamless coordination between the two components of the firefighting system. With all systems in place, the drone gracefully lifts off the ground, its movements controlled with precision as it navigates towards the desired location.

Upon reaching the designated spot, the drone's camera captures an initial image of the fire, providing valuable insights into its intensity and spread. With this data in hand, the next step is critical - the release of the extinguishing capsules from the dispenser. The capsules are deployed strategically, aimed at suppressing the flames effectively.

Following the release of the capsules, the drone captures a final image of the fire, documenting the immediate impact of the extinguishing agent. Remaining vigilant, the drone hovers in the vicinity of the fire, observing any potential flare-ups or changes in the situation.

Once it's determined that the fire is under control and the area is safe, the drone is directed back to the user's location. With its mission accomplished, the drone lands smoothly, ready to be prepared for future firefighting operations. Through meticulous execution and technological prowess, the drone has played a pivotal role in combating the blaze, contributing to the preservation of life and property.

VI. EXPERIMENTS & DISCUSSION:

In the experimentation phase conducted on the drone model, two crucial variables under examination are the height from the target and the distance from the desired point. These variables play significant roles in determining the effectiveness and efficiency of the drone's firefighting capabilities.

Height from the target refers to the altitude at which the drone operates relative to the fire source. Through systematic testing, different altitudes are explored to identify the optimal height for extinguishing fires of varying sizes and intensities. Higher altitudes may provide broader coverage but could compromise precision, while lower altitudes offer more targeted suppression but risk exposure to heat and debris.

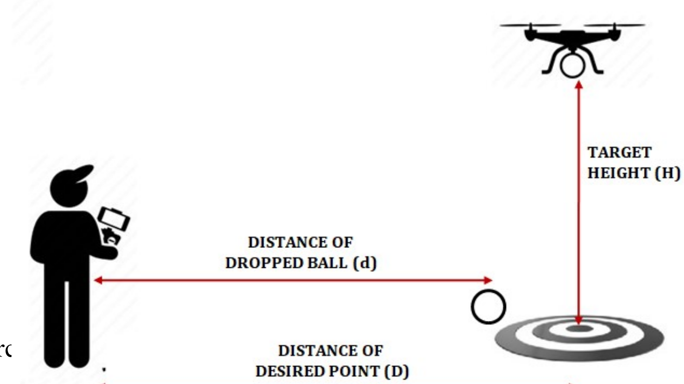

Fig 5: Experiment Methodology

Distance from the desired point refers to the proximity of the drone to the designated location for firefighting operations. This variable influences the drone's maneuverability, response time, and overall effectiveness in reaching the target area swiftly and accurately. Experimentation involves assessing different distances to determine the ideal balance between proximity and safety, ensuring that the drone can reach the fire quickly without compromising its operational integrity.

In addition to height and distance, the response time of the extinguisher release mechanism is a critical parameter evaluated during experimentation. This entails measuring the time elapsed between the initiation of the extinguishing process and the actual release of the extinguishing agent from the drone's dispenser. Precise timing is essential for timely intervention and effective suppression of fires, minimizing potential damage and risk.

S. NO	TRIAL NO	TARGET HEIGHT	DISTANCE OF DESIRED POINT (D)	AVERAGE RESPONSE TIME	DISTANCE OF DROPPED BALL (d)	ERROR %
		m	m	sec	m	
1	TRAIL 1	2.00	2.00	0.942	1.980	5.51
2	TRAIL 2	2.00	3.00	0.898	2.924	4.93
3	TRAIL 3	3.00	3.00	0.954	2.780	5.33

Table 1: Experimental Reading

VII. RESULT & CONCLUSION

Based on the findings derived from our experiments, it is unequivocally evident that the firefighting drone outfitted with a ball extinguisher operates with remarkable efficiency. The average response time of the drone, clocking in at 0.931 seconds, underscores its rapid deployment and swift action in combating fires. This near-instantaneous reaction time is instrumental in containing and extinguishing fires swiftly, minimizing potential damage and hazards.

Moreover, the drone exhibits an impressive target accuracy range of 93% to 95%. This level of precision highlights the drone's capability to effectively target and deploy the extinguishing agent with a high degree of accuracy. Such accuracy is crucial in ensuring that the firefighting efforts are focused and impactful, effectively suppressing the flames and mitigating the spread of fire.

This paper introduces a cost-effective drone concept for aiding firefighters during wildfires, expanding its applications beyond traditional uses like search and rescue. Unlike other proposals, our drone not only surveys but also directly interacts with fires, serving as a firefighter assistant. Experimental results validate objectives such as reaching desired height, maintaining flight stability, and effectively covering fire-affected areas. Future work involves determining the minimum safe distance between the drone and fire using temperature monitoring. Additionally, stability enhancements are planned for the next prototype iteration. This drone, capable of carrying up to 200g payload with 21 minutes of battery endurance, significantly reduces risks to firefighting personnel. Equipped with a thermal imaging camera, it can also detect individuals trapped in forests during wildfires.

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