



Involvement of Drone Technology and Fire Extinguishing Balls in Firefighting

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ABSTRACT

Since the discovery of fire, humanity has been engaged in a perpetual battle against its destructive force, spanning millennia. This paper explores the potential integration of fire extinguisher balls into a proposed system, where drone and remote-sensing technologies, such as unmanned aerial vehicles (UAVs), are employed collaboratively to complement traditional firefighting methods. Throughout history, the primary objective has been to extinguish fires swiftly and develop materials resistant to combustion. Multidimensional signal processing, including the utilization of timed acoustic waves, holds promise as a novel approach to fire suppression. Furthermore, the paper presents updated insights into flame retardants, encompassing advancements in basic sciences. From inherently fire-resistant materials to flame-retardant additives and nanocomposites, emerging processes and applications are briefly discussed, reflecting the ongoing pursuit of innovative solutions to mitigate the impact of fires.

Keywords: drones, fire extinguishing balls, remote sensing, sensor, surveillance, firefighting, flame extinction

Introduction

Fire incidents are getting more dangerous, complicated and larger-scaled, making it more difficult for humans first-responders to act. A potential technical solution could be planned the unmanned firefighting equipment, to avoid substantial damage. Drone technology is potentially be applied for several purposes within firefighting practices, such as monitoring of potential danger, detection of danger with the help of thermal imaging cameras and real-time cameras for extinguishing fire. Drone technology companies are looking for potential applications and business cases for the use of drone technology in this field. Application of drone technology for firefighting, where there is still much ground to cover aspects such as commercialization and technology development.

Therefore, the research questions of this paper will read:

- What could be potential ways to detect and the fire related issues?
- What could be done to enhance drone technology for firefighting?
- And what must be done to develop these and make use of them efficiently?

The aim of this research is to give a clear overview about the opportunities that lie within the field of firefighting drones, and how to further develop these opportunities.

Fire can be described as a chemical process involving the high-temperature oxidation of a flammable substance, known as fuel. This reaction releases energy and generates heat. The initiation of fire requires four essential elements: oxygen, fuel, heat, and chemical reactions, collectively forming what is known as the fire tetrahedron. To sustain a fire, both the oxidizer and fuel supply must remain present. Consequently, the heat produced by the combustion reaction allows the fire to maintain its temperature, facilitating the chain reactions necessary for its propagation. The traditional stages of fire development, depicted in Figure 1, illustrate the progression from an initial phase where no flames are visible, characterized by soldering, to subsequent stages involving

ignition and flaming with adequate ventilation. For continued growth, fire necessitates a steady supply of new or suitable fuel and oxygen mixture. As the fire reaches the flashover point, it rapidly spreads by acquiring sufficient oxygen, fuel, and heat. Once the fire reaches the fully developed phase, available fuel becomes depleted, leading to the cessation of combustion. Extinguishing a fire becomes increasingly challenging after the flashover point is surpassed.

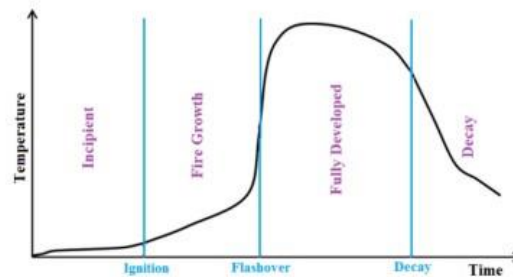


Figure1.

https://encyclopedia.pub/media/item_content/202203/polymers1401224g001-62391ee16800c.png

Unmanned aerial vehicles (UAVs), or drones, are high-end cyber-physical systems (CPSs) for numerous data collection and monitoring tasks because of their capability to perform complex computations via wireless communication channels, high mobility, and automated operation. UAVs can serve as internet of things (IoT) devices for data sharing, provide real-time data for input into 'big data' applications, and enable efficient decision-making. UAVs are one of the advanced technologies that, along with the other technologies, are used to manage smart cities. Classified UAV applications into data covering, e.g., surveillance and event covering, data relaying, e.g., delivery and emergency services. The surveillance task is about monitoring a target, which can be a person, a group of people, behaviors, activities, air pollutants, infrastructure, or buildings, and its typical applications are border patrol, construction management, power grid inspection, traffic monitoring, etc. UAVs can perform complex surveillance tasks is a more beneficial and sustainable option because they can cover large and different areas to encounter with ease.

Unmanned Aerial Vehicles (UAVs) find extensive application across various fields, offering versatility in executing tasks that pose challenges or risks to human safety. In the context of fire departments, numerous studies have explored the integration of Unmanned Aircraft Systems (UAS) to alleviate the burden of firefighting efforts. While firefighter drones primarily concentrate on site monitoring through camera surveillance, there has been a push to equip them with fire extinguishing capabilities.

Some researchers have proposed a solution involving tethering the drone to the ground via a hose, facilitating access to a large water container. This setup allows the drone's tank to be replenished directly from the container. However, a notable drawback encountered with this approach is the inherent limitation imposed on the drone's movements due to the connection to the ground via the water container.



Figure2. [https://www.researchgate.net/profile/MichaelStarek/publication/331047112/fig-](https://www.researchgate.net/profile/MichaelStarek/publication/331047112/figure/fig2/AS:725541506252801@1549993983256/AFO-and-Elide-fire-extinguishingballs-8-9.jpg)

[ure/fig2/AS:725541506252801@1549993983256/AFO-and-Elide-fire-extinguishingballs-8-9.jpg](https://www.researchgate.net/profile/MichaelStarek/publication/331047112/figure/fig2/AS:725541506252801@1549993983256/AFO-and-Elide-fire-extinguishingballs-8-9.jpg)

Fire extinguisher balls serve as a crucial tool in mitigating the spread of flames, offering a swift response to fire outbreaks. In the past, glass balls containing fire suppressant liquids were utilized for firefighting purposes. However, with evolving preferences, the traditional "glass ball" design fell out of favor among consumers. Today's fire extinguisher balls have evolved, featuring a foam casing encased in poly-vinyl chloride (PVC) and containing a dry chemical fire suppressant. Activated by heat or flames, triggers within the unit prompt an immediate dispersal of the suppressant, typically mono-ammonium phosphate, capable of extinguishing class A, B, or C fires.

The significance of these fire extinguisher balls lies in their ability to assist firefighters in containing and extinguishing fires, while also offering a real-time monitoring system for areas at risk. The overarching

objectives of the study revolve around designing and developing an unmanned aerial vehicle (UAV) to support firefighting efforts. Equipped with a gyroscope for flight stabilization, the UAV ensures steady flight post-shooting, automatically transitioning into a stable mode if remote control signal is lost. Real-time video streaming, accessible through the controller's LCD, facilitates monitoring of designated areas or buildings.

Operating with a flying time of up to fifteen minutes, the UAV boasts a carrying capacity of up to five kilograms and a flight range of one kilometer from the controller without interference. With a maximum speed of fifty miles per hour, the prototype is limited to carrying two fire extinguisher balls simultaneously due to resource constraints.

1 Objective

There is already a modular framework, where each module is designed to perform one task. The application of drone technology for firefighting is to mount camera systems like hyperspectral, thermal, and infrared cameras to the drones to be able to monitor and detect potential fire incidents. These camera systems could warn first-responder teams or assist them while they are doing their job. Warning first-responder teams before the fire spreads can be of crucial importance in many incidents. Next to faster detection of fire, it could lead to cost savings.⁵ New sensors and miniaturization of existing sensors promise to increase the range of application they could have. There are several uses of such sensor assisted drones.

One use could be the application of these drones in wildfire detection. In Present scenarios inferior solutions for the detection of the wildfires are being used. Watch towers for the monitoring of wildfires are inflexible, expensive and cannot cover a large area. Satellite footage is often too inaccurate, and therefore will not be able to warn first-responder teams before the fire spreads. The other option for the monitoring of wildfires are manned aircraft such as helicopters and planes, which represent a much more expensive firefighting solution than the sensor assisted drones.

Drones will be able to cover a vast area and have a perfect accuracy for detecting the beginning of a wildfire.⁶ Another possible area of application of these drones that are equipped with sensor systems is the detection of subterranean fires. Drones that are mounted with a thermal infrared detector can detect the heat transferred to the surface above a fire. Research shows that these drones will have a very accurate detection of fire, even flying at heights up to 250 meters above ground. They should be able to detect both open and covered fires. Our solution also proposes mission planner algorithm for activating and deactivating each module when needed. In the competition, we tested our approach in the virtual environment, obtaining first place in the classification phase.

Moreover, we brought the system into the real environment with great results, winning the finals against other finalist teams from around the world. In this paper, we describe our approach and the solution developed for this challenge. The main contribution of this work is the design of a framework that can be used in a simplified urban firefighting mission. Besides, we would like to highlight the mission planner that provides a structured behavior to the solution, a seek strategy for target detection, and a throwing maneuver using speed commands.

2 Related Work

The conceptual framework elucidates the system's operational flow through the lens of input-process-output dynamics, wherein the user commands the UAV's flight and monitors the surroundings using a designated controller. Facilitating this communication is a radio frequency transmitter, serving as the conduit between the UAV and the controller. Within the UAV's architecture, a radio frequency receiver is seamlessly integrated into the microcontroller to intercept and interpret incoming signals. Further enhancing user interface, the controller's LCD screen establishes wireless connectivity with the UAV's embedded microcontroller.

Operating at the heart of the UAV's functionality is the embedded microcontroller, orchestrating adjustments to the servo motor and orchestrating the activation of the shooting and dropping system. Notably, the project adopts the octocopter configuration, characterized by eight rotating arms, each housing a rotor. A critical aspect of this setup is the rotational direction of the propellers affixed to the craft's rotors. Conventionally, the propellers on each rotor spin in opposing directions—while one rotates clockwise, its counterpart rotates counterclockwise—ensuring optimal balance and stability during flight. The communication backbone of this system rests on a radio frequency transmitter, serving as the conduit between the user's commands and the UAV. Crucially, a radio frequency receiver is seamlessly integrated into the UAV's microcontroller, acting as the sensory interface that captures and interprets the signals transmitted by the user through the controller.

Ensuring a dynamic and user-friendly interface, the controller's LCD screen establishes a wireless connection with the microcontroller embedded within the UAV. This wireless link allows for real-time data visualization, empowering the user with immediate insights into the UAV's operational status and the surrounding environment.

The microcontroller, functioning as the brain of the operation, plays a pivotal role in executing user commands. It not only translates the received signals into actionable instructions but also manages the intricate adjustments of servo motors. These adjustments are crucial for fine-tuning the UAV's orientation and ensuring optimal performance during flight. Moreover, the embedded microcontroller orchestrates the activation of the shooting and dropping mechanisms, adding a layer of functionality to the UAV beyond mere surveillance.

Table 01 – Relate work to Drone Technology and Firefighting

Author(s)	Research Context	Problem Statement	Key Findings	Future Scope
Hossain et al. (2019)	Developed a system that combines a drone (UAV) with a web app.	Utilize realtime monitoring and control systems to mitigate urban traffic congestion effectively.	The system empowers users to choose the route with the fewest vehicles available.	Integrate Convolutional neural networks (CNNs) with the model to enhance data gathering and image processing.
De Frias et al. (2020)	Suggested a collaborative system utilizing UAVs and a compact semantic neural network.	Employing UAVs to address challenges associated with stationary sensor installations.	The suggested approach demonstrated resilience and efficacy.	Introducing a model capable of identifying every element on the road to achieve comprehensive road coverage.
Burchan Aydin (2019)	Exploring the integration of fire extinguishing balls with drone and remotesensing technologies to enhance firefighting methods.	Assessing the effectiveness of small-sized fire extinguishing balls attached to drones combating building fires versus wildfires.	Small-sized fire extinguishing balls may not effectively combat building fires but can extinguish short grass fires, suggesting a focus on wildfire fighting.	Further development of heavy payload drones and apparatus for carrying fire-extinguishing balls to improve firefighting capabilities.
Jacek Lukasz Wilk-jakubowski (2022)	Exploring the use of acoustic waves for flame suppression and advancements	Addressing the challenge of effectively extinguishing fires and developing fire-	Acoustic waves show promise for flame suppression, with advancements	Use of acoustic waves develop innovative flame-retardant materials for enhanced fire
	in flame-retardant materials.	resistant materials.	in flame retardants materials.	suppression capabilities.
David PerezSaura	Expanding the use of unmanned aerial vehicles (UAVs) for firefighting applications due to their safety and rapid response capabilities.	Limited research on UAV utilization in urban firefighting scenarios, prompting the need for exploration and development.	Successful development of a modular solution for UAV-assisted firefighting, winning first prize in an international competition.	Further refinement and implementation of UAV-based firefighting systems for urban environments to enhance firefighting effectiveness and safety.

Adel Gohari (2022)	Examining the role of surveillance drones in supporting the sustainability goals of smart cities.	Lack of comprehensive understanding of the status and potential applications of surveillance drones in smart cities.	Surveillance drones are predominantly utilized in air pollution and traffic monitoring, with potential for efficient and sustainable solutions.	Further exploration and integration of surveillance drones with emerging technologies to enhance their effectiveness in supporting smart city initiatives.
Nastaran Reza Nazar Zadeh (2021)	Addressing challenges faced by firefighters in reaching the top floors of high-rise buildings in smart city environments.	Overcoming delays in delivering heavy firefighting equipment due to urban traffic congestion, hindering effective firefighting operations.	Development and testing of a firefighting UAV equipped with a fire extinguishing ball shooting and dropping mechanism, with night vision camera.	Optimization and refinement of firefighting UAV technology to improve stability, functionality and effectiveness in combating fires in highrise buildings within smart city environments.
Seo et al. (2018)	Examine various bridge types for damage using a UAV.	Reduce the time consumption in inspecting bridge types using UAVs.	Various types of bridge damages can be identified through UAV inspection,	Implement this methodology to diverse bridge types, employing image analysis-
			particularly in areas inaccessible to traditional inspectors.	based quantification methods to detect damages.
Shang et al. (2019)	Suggested a platform offering defect detection utilizing both aerial and ground image inspections.	Development of a data fusion platform for integrating multi-scale images.	The Proposed platform facilitates the detection, description, and localization of surface and subsurface bridge deck defects.	Extend the platform's capabilities to cater to pavement and tunnel applications.

Pan et al. (2020)	Developed a system for optimizing the utilization of big image data to detect broken power strands efficiently.	Detecting broken power strands is crucial for ensuring the integrity and safety of power transmission systems.	Random forest (RF) excels in homogenous views, while neural networkbased algorithms perform better in heterogeneous and semi-heterogeneous scenarios.	Enhance the accuracy and stability of the proposed system through adjustments to model parameters and architecture details.
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One of the distinctive features of the project is the adoption of the octocopter concept, characterized by eight rotating arms. This choice in design is not arbitrary; it has profound implications for the stability of the UAV. The rotational direction of the propellers affixed to each rotor becomes a significant consideration. In adherence to a fundamental principle, adjacent rotors are engineered to rotate in opposite directions. This means that while one rotor spins clockwise, its neighboring rotor spins counterclockwise. This design consideration is pivotal for achieving the desired balance and control in the UAV's flight.

Expanding the scope of this technological endeavor, it is essential to delve into the intricacies of the shooting and dropping system triggered by the embedded microcontroller. This system, integrated into the UAV, introduces a multifunctional capability, going beyond conventional surveillance. The precise orchestration of servo motors plays a crucial role in the accurate deployment of the shooting and dropping mechanisms. These mechanisms open possibilities for various applications, from data collection to payload delivery, making the UAV a versatile tool for diverse scenarios.

As we reflect on the broader implications of this UAV system, it becomes evident that it transcends the realm of a mere technological showcase. It serves as a tangible example of human-machine collaboration, where user inputs translate into tangible actions performed by the UAV. This collaborative synergy is exemplified by the seamless integration of hardware components and the user interface, offering a holistic and user-centric solution.

Furthermore, the octocopter design choice reflects a nuanced understanding of aerodynamics and stability in UAVs. By adhering to the principle of opposing rotations in adjacent rotors, the design maximizes stability and control, crucial factors in ensuring the UAV's safe and effective operation.

In conclusion, the conceptual framework presented encapsulates the essence of a UAV system. From user control and communication via radio frequency to wireless display and embedded microcontroller operations, every facet of the system is meticulously designed to offer a seamless and user-friendly experience. The adoption of the octocopter concept and the deliberate choice in propeller rotation directions underscore the project's commitment to achieving optimal performance and stability. Beyond its technical prowess, this UAV system stands as a testament to the possibilities unlocked through thoughtful integration of technology, enhancing human capabilities in diverse scenarios.

3.1. UAV concepts

An innovative servo mechanism has been intricately integrated into the arm rotor of the copter, ushering in a new era of precise control over its directional movements. Marked with distinct yellow tape, the front side of the arm serves as a visual cue for orientation, ensuring seamless navigation through the skies. This sophisticated mechanism operates synergistically with applied thrust and motor movements, dynamically adjusting for roll, pitch, and yaw to maintain optimal flight dynamics. As the arm rotates, its capacity to carry payloads increases proportionally, facilitating the transportation of heavier equipment with remarkable efficiency. To fortify the copter's aerial stability, a cutting-edge gyroscope has been seamlessly incorporated into its design. This gyroscope not only measures rotations around the x, y, and z axes but also plays a pivotal role in maintaining steady flight by accurately tracking changes in angular velocity. Using a small proof mass, the gyroscope ensures precise readings, contributing to the UAV's overall stability and maneuverability. Furthermore, the integration of a barometric pressure sensor adds another layer of functionality to the UAV's sensor suite. This sensor provides crucial altitude data during flight, enabling the copter to adjust its trajectory with unparalleled precision. By leveraging real-time atmospheric pressure readings, the UAV can navigate through varying altitudes with ease, even in challenging environmental conditions.

In addition to these advanced sensors, the UAV is equipped with a GPS sensor that relies on signals from satellites in medium Earth orbit (MEO). Positioned approximately 20,180 km above the Earth's surface, these satellites provide essential navigational data, allowing the copter to accurately determine its position and course. However, despite the robustness of these systems, occasional navigation issues may arise due to GPS glitches. These glitches, primarily caused by signal unavailability or interference, can result in insufficient GPS data, leading to navigational inaccuracies. In instances where the glitch persists for an extended period, the

reliability of location values may be compromised, posing challenges for the UAV's prototype design and operational efficiency. Therefore, while the integration of advanced sensors has undoubtedly enhanced the copter's capabilities, addressing and mitigating GPS glitches remain critical areas of focus for further development and refinement.

3 Conclusion and Future Scope

As the successful completion of project, an innovative Unmanned Aerial Vehicle (UAV) has been meticulously crafted and operationalized. This UAV boasts a distinctive shooting and dropping mechanism, ingeniously fashioned from PVC materials, specifically tailored for dispensing fire extinguisher balls ranging from class A to C. Equipped with an HD camera featuring night vision capabilities, seamlessly integrated with real-time video streaming via a 5.8 GHz radio frequency (RF) signal, the UAV empowers firefighting teams with enhanced targeting precision. Throughout the study, a remote controller utilizing 2.4 GHz RF signals has been employed to manipulate the shooting and dropping mechanisms, alongside facilitating control over the UAV's movements. Furthermore, the integration of a gyroscope and GPS module serves to bolster flight stability, ensuring optimal performance.

In conducting experiments, rigorous testing was conducted to evaluate the UAV's hardware components and the efficacy of its shooting and dropping mechanisms during flight operations, yielding an impressive overall passing rate of 97.22%. Notably, one of the notable challenges encountered during testing pertained to the UAV's susceptibility to weather conditions, underscoring the need for robustness and adaptability in its design and operation. The UAV has some pretty neat features. First off, it has a hightech camera with night vision, kind of like superhero goggles but for a drone. This camera streams videos in real-time, helping the firefighting team see where to aim and shoot the fire extinguisher balls. We also use a radio frequency signal (5.8 GHz) to communicate with the UAV, telling it what to do and when to shoot.

To control this flying firefighter, we have a remote control using a 2.4 GHz signal. It's like a fancy video game controller that not only manages the shooting and dropping system but also guides the UAV's movements in the air. We added a gyroscope to keep the drone steady and a GPS module to help it know where it is.

Now, we put our creation to the test. We checked how well the UAV works in terms of its parts, shooting, and dropping mechanism during its flight. Guess what? It passed with flying colors. We got a fantastic 97.22% passing rate. But, you know, making things isn't always easy. We faced a challenge during our tests – the UAV is a bit picky about the weather. Weather conditions can mess with its shooting accuracy, so we need someone skilled to take over the controller when things get tricky.

Here's an important thing to note: our fire-extinguisher balls are like superhero sidekicks. They're great for helping in smart cities where we have other firefighting tools.

But they're not superheroes on their own. They need some help.

Looking ahead, we have some cool ideas to make our UAV even better. We're thinking of using 3D printing to make the shooting system, so it can carry more fire extinguisher balls each time it takes flight. And hey, everyone needs a bit more energy, right? So, we're planning to add an extra battery to boost the UAV's power and make it last longer.

In a nutshell, our UAV is a flying hero, but it's not perfect. It needs someone smart to guide it, especially when the weather gets moody. With a bit more tinkering and some cool upgrades, we're excited to see how our flying firefighter can become an even greater hero in the future! And who knows, maybe one day it'll be part of the squad that saves the day in every smart city. Until then, we're proud of our UAV and its journey to become a firefighting superstar!

Hence, operating the UAV controller demands skilled expertise, underscoring the need for adept individuals at the helm. Additionally, while fire-extinguisher balls serve as valuable tools in firefighting challenges within smart cities, they should be viewed as supplements rather than standalone solutions. To advance this study, researchers could explore utilizing 3D printing technology to enhance the shooting mechanism, allowing for increased carrying capacity of fire distinguisher balls per flight attempt. Moreover, extending battery life could be achieved by incorporating an additional battery.

In evaluating performance, rigorous testing was conducted on both the hardware and software components of the UAV and shooting mechanism. Table 2 presents the results of functionality tests, revealing an impressive average passing rate of 97.22%. Throughout these tests, researchers encountered challenges in UAV control, particularly in adverse weather conditions, impacting the drone's shooting accuracy.

Further insights into shooting distance and battery life are detailed in Table 3. Notably, battery duration was longer when the UAV was grounded due to the comprehensive support required by its components. Figure 4 provides visual documentation of the prototype, capturing moments during functionality tests in both ideal (grounded) and flying modes.

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