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Firefighting in Smart Cities - Unmanned Aerial Vehicle with Fire Extinguishing Ball Launch and Liquid Dispensing System

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ABSTRACT:

Firefighting is one of an important field where drones may have a significant influence. The Internet of Things, or IoT, is expanding quickly in a number of industries, and it plays a crucial role in addressing the challenges posed by high-rise fires. High-rise fires are often inaccessible to ground vehicles due to various constraints, and many skyscrapers lack adequate methods for preventing and monitoring fires. To tackle this issue, this article proposes the use of Unmanned Air Vehicles (UAVs) to prevent such incidents. This system integrates IoT technologies with UAVs that are launched from the Fire Control Unit (FCU). Sensors installed in the skyscraper detect the presence of a fire and promptly transmit distress signals to the command and control unit. The flight path of the UAV is continually observed by the pilot at the FCU, who also obtains video and fire scan data from it. When a distress signal or fire alert is detected, the system utilizes Global Positioning System (GPS) technology to pinpoint the skyscraper's location. Afterwards, a request is made to the appropriate security agency to authorize the deployment of a fire extinguisher truck. Upon receiving authorization, the system enters the geographical coordinates and the closest fire station deploys the unmanned aerial vehicle (UAV) to the specified site. The UAV deploys fire suppressants and then returns to the nearest landing site to reload with another fire suppressant for subsequent use. This proposed methodology aims to enhance the Quality of Service and improve the effectiveness of firefighting operations in high-rise buildings.

1. Introduction

Drones are an essential aerial tool for firefighters. For individuals working in the fire service, they are an essential tool, especially in cities where there is a genuine risk of a serious fire in a high-rise structure. Cutting-edge technology is made available to fire authorities by firefighting drones, which enhance and complement the capabilities of current resources like as fire engines, ladders, specialist gear, and more. In the context of smart cities, the fast growth of metropolitan areas and technological advancements have created a growing number of issues for firefighting services. Reaching the top levels of big buildings is one major obstacle. To reach high altitudes, firefighters often need huge, heavy equipment, and sometimes, timely delivery becomes problematic-mainly because of transportation congestion in densely populated areas. This initiative aims to use drone technology to assist with battling fires.

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We have carefully considered all of the required features and specifications before designing a multi-copter with a fire extinguisher system. The drone's internal camera allows firefighters to observe the fire location effectively while operating it from a safe distance. Users may direct the drone to distribute the extinguishing liquid to control the fire after the target has been detected.

The incorporation of drones into firefighting crews was examined by the authors in their research [1]. They proposed a Human-Drone Interaction approach that uses gestures to facilitate direct communication between firefighters and drones. Buildings, whether residential and commercial, depend heavily on firefighters to maintain their safety [2]. Arrival delays for firefighters are common, and one reason for this is the increased traffic that happens when a fire starts to spread. When it comes to their operations, high-rise structures also provide a big difficulty to firemen [3]. Due to fast urbanization and limited land availability, Number of emerging countries have seen a considerable rise in the proliferation of tall structures and commercial hubs, resulting in close proximity of buildings. The confined space found in urban areas makes it difficult to facilitate and coordinate firefighting efforts [4]. Figures 1 and 2 realistically represent the quantity of fire calls and the associated total number of lives saved and lost during the last five years, based on data published by the Tamil Nadu government [5].

A firefighting drone's ability to battle fires in a safe, cost-effective, and environmentally-friendly manner, as well as its ability to retain operational performance over time, are all parts of its sustainability. The sustainability of a firefighter UAV involves a comprehensive strategy that takes into account its regulatory compliance, cost-effectiveness, safety, resource conservation, operational efficacy, long-term durability, and environmental impact.

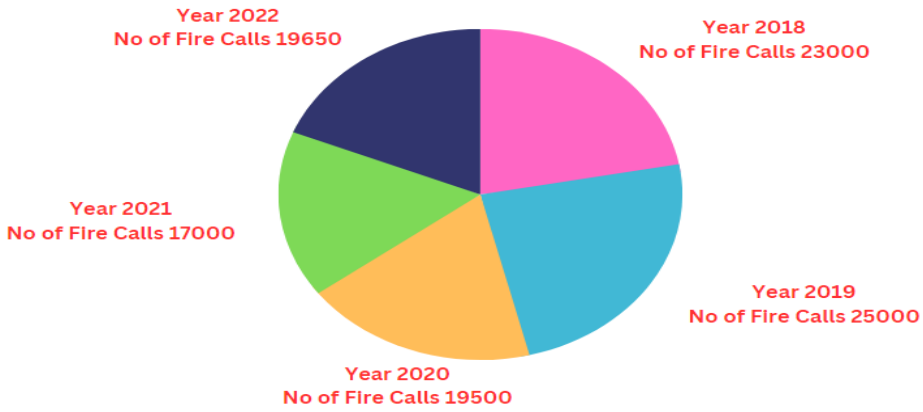

Figure 1. Number of fire - calls in last 5 year

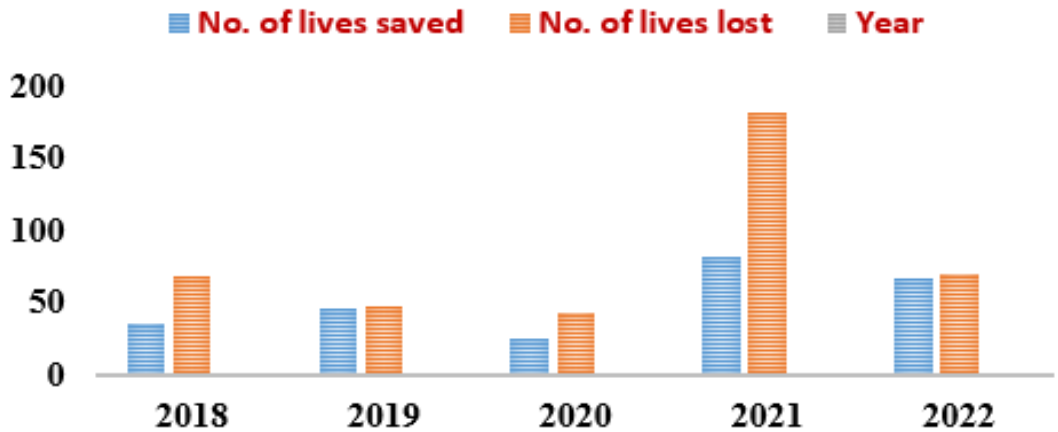

Figure 2. No. of lives saved & lost in last 5 years

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In order to control wildfires while limiting harm to the environment and available resources, a sustainable firefighting drone should be an invaluable tool. Drones in particular are a potential unmanned firefighting tool for reducing fire damage and safeguarding first responders. The effective handling of fire events and the effectiveness of firefighting operations might both be improved by the deployment of autonomous firefighting equipment. Drones may be used in firefighting for a variety of tasks, such as spotting threats, monitoring possible risks, and putting out flames. Drones fitted with real-time and thermal imaging cameras can monitor possible threats efficiently, depending on the circumstances of the particular occurrence. Additionally, studies are being conducted to determine how well drone swarms and payload-dropping drones work to put out fires [6]. By deploying drones equipped with the right camera, sensors, and integration modules, drone applications may be made more efficient [7]. The Sustainability of firefighting Drone is displayed in Figure 3.

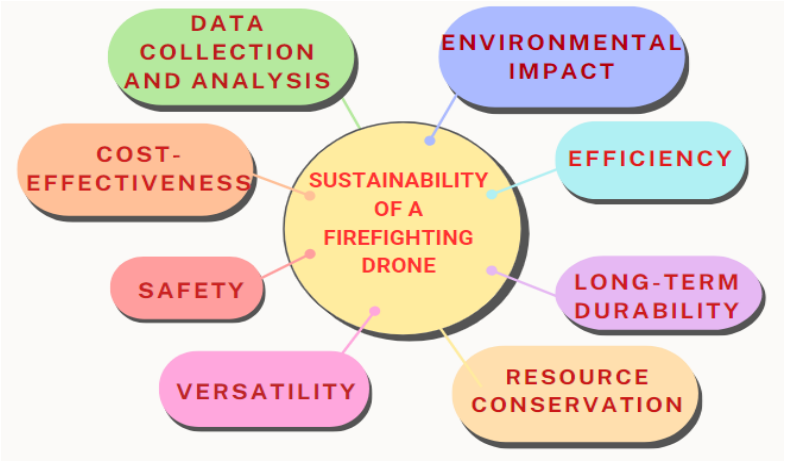

Figure 3. Sustainability of firefighting Drone

Drone use in firefighting operations may greatly increase the safety of firefighters. Firefighters can recognize and steer clear of any threats thanks to the real-time aerial photos that drones offer of the fire and its surroundings. Drones also provide firemen on the ground with ongoing information, enabling them to use their resources more strategically and with more knowledge. Drones for battling fires have a lot of potential benefits, but there are still a few issues that need to be resolved. Making sure drones can function properly in hot conditions and endure being near flames and smoke is one such problem [8]. They also need to be able to maneuver around hazardous areas like woods and buildings without being hurt. It is necessary to take into account extra legal and regulatory issues. Drone usage in firefighting is presently strictly controlled, with restrictions on where and how it may be deployed. However, as technology develops further, it is expected that these regulations will loosen up and permit the increased use of drones in firefighting operations [9]. The suggested technology aims to extinguish fires in a very efficient manner in order to avert significant losses. The need of robust fire safety cannot be overstated in residential areas. To mitigate challenges encountered in the field and guarantee a secure approach to firefighting, a novel approach has been implemented by integrating Internet of Things with Firefighting Drone technology.

2. Related works

The new goal of firefighting drones is to give a faster and more efficient way to put out fires. Drones, which can provide real-time information on the location and severity of the fire, may help firefighters make better decisions on how to combat the fire. Firefighters may benefit from the usage of drones to deliver equipment and supplies like water and fire extinguishers. Another growing application for firefighting drones is to reduce hazard to firefighters. Drones are used in many different fields, including science, research, security, surveillance, and search and rescue. Using a drone to combat fires expands research opportunities and enhances quality of life. Drones for combating flames are an essential instrument in the battle against high-rise

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building fires. These drones may provide firefighters with essential information and support, allowing them to extinguish fires more skilfully and safely. The ability of firefighting drones to provide real-time data and images from the air is one of its main advantages. In 2018, Alshbatat completed a research that presented a quadrotor intended for use in battling fires. Using a servo motor, this quadrotor can simultaneously release four fire extinguisher balls. Notable for its small, horizontal shape, the payload release mechanism may be integrated with a variety of drones. It also shows less vulnerability to vibrations while in flight [10].

The high-rise firefighting drone's kinematic model is built using the Newton-Euler technique, guided by the assumptions outlined in the research conducted in 2020 by Vinh et al. Three main facets are the focus of these presumptions. Initially, the drone is handled as a symmetrical, rigid solid, purposefully ignoring elastic deformation resulting from its frame construction. According to this paradigm, the apparatus is a solid, stable object by nature. Second, any aerodynamic effects resulting from blade flapping are essentially eliminated since it is believed that the drone's propellers are solid. Finally, the model purposefully ignores the influence of ground effect [11]. The drone was designed mainly to fight fires; it has gas extinguisher and water sprayers. It can effectively put out fires in enormous buildings and reach considerable heights because to its range of operations [12]. ML is the experimental study of various statistical models and algorithms to carry out certain tasks without the need for categorization structure, instead relying on pattern and assumption. Put differently, machine learning is all about teaching a computer to recognize various types of data [13]. The first stage of the Internet of Things (IoT) may be seen as the present revolution in mobile, Internet, and machine-to-machine technology. By linking physical items together to facilitate intelligent decision-making, the Internet of Things (IoT) is anticipated to bridge disparate technologies in the years to come [14]. There is a greater demand for UAV technology research and development as a result of the disruptive innovation seen in civilian drone (UAV) applications nowadays. UAV flight controller hardware and software are closely tied to UAV platform qualities including endurance, fault tolerance, functionality, and dependability. These are the main concerns that are presently being addressed [15]. Using a quadrotor unmanned aerial vehicle (UAV) and integrated atmospheric multi-parameter sensor that is lightweight and low-power, it is possible to sample the vertical distribution of aerosols while also measuring temperature, relative humidity, atmospheric pressure, and aerosol particle concentration [16]. The drones are equipped with appropriate cameras, sensors, and integrated components that enable them to achieve transparency and efficiency. Drones are increasingly using the Internet of Things (IoT) and cloud computing, which has increased productivity via cost management, performance monitoring, and maintenance. Growers have benefited greatly from this due to the improved agricultural output and effective use of resources [17].

Worldwide, the number of unplanned fire events is rising as a result of factors including electrical short circuits, cooking fires, irresponsible smoking, and mishaps involving kids playing with candles and matchsticks. Identifying fires using data on smoke and combustion is essential to developing better firefighting strategies in these kinds of situations. The probability of fire occurrences increases with modern building construction, such as in apartment complexes with a higher resident count. In these situations, those within the building might find it difficult to leave securely. Drones used for battling fires come in quite handy in this situation. Firefighters face many difficulties during evacuation because of the large vertical distances they have to travel. Traffic jams frequently make it difficult for them to arrive on time, which can result in serious property damage and even fatalities.

Problem Statement

Fire incidents worldwide have been rising unexpectedly due to factors such as electrical short-circuits and human errors such negligent smoking, kitchen fires and youngsters playing with matches and candles. The occurrence of a fire often induces a state of fear among individuals, resulting in disorganized and frenzied actions rather than effectively dealing with the emergency. Moreover, insufficient fire safety protocols lead to significant deaths. The building of contemporary apartment complexes that can accommodate greater people has increased the danger in the case of a fire breakout. The lack of understanding among residents about safe evacuation procedures in such structures might worsen the issue. The introduction of firefighting drones might provide significant aid in such situations. Firefighters face formidable obstacles during evacuations, such as road congestion that sometimes hinders their prompt arrival, leading to considerable

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property destruction and loss of life. Firefighters have considerable difficulties when it comes to accessing and putting out fires in tall structures or crowded urban areas. Fires not only imperil the lives of people trapped inside but also put the firemen at risk while tackling the flames. Places such as hospitals, tall residential buildings, hotels, and commercial complexes are notable instances when fire events occur, posing increased hazards for both the people impacted and the firemen. Strong fire protection is very important, and dwelling areas should prioritize this. Interfacing Internet of Things with Firefighting Drone technology is a unique technology that has been utilized to prevent field issues and guarantee a safe manner of fighting fires.

3. Methodology

With this technique, a drone may carry a liquid nozzle and a fire extinguisher ball. The drone is medium category enabled with tethered power. The drone contains fire extinguisher ball and fire extinguisher sprayer system. The spraying liquid delivered from the tank through nozzle and the fire extinguisher ball launched from the cartridge which is loaded in drone. For this to function correctly, the fire extinguisher ball has to be dropped down at the appropriate place. The nozzle applies the liquid or foam fire extinguisher to the necessary locations where the fire erupted. The drone should be able to connect to the internet and use location coordinates to update its position on a regular basis. The drone should have a camera and a collision avoidance sensor built into it, and it should fly steadily. The high-rise skyscraper that is the starting point of the Figure 4 suggested strategies for deploying this technology is on fire. Firefighters find it challenging to get to the fire and put it out. The firefighting drone can be outfitted with a variety of camera systems, including the FLIR-developed Zenmuse XT camera, which has a 360-degree rotational ability and an efficient coupled aerial camera with a 30x optical zoom and a 6x digital zoom.

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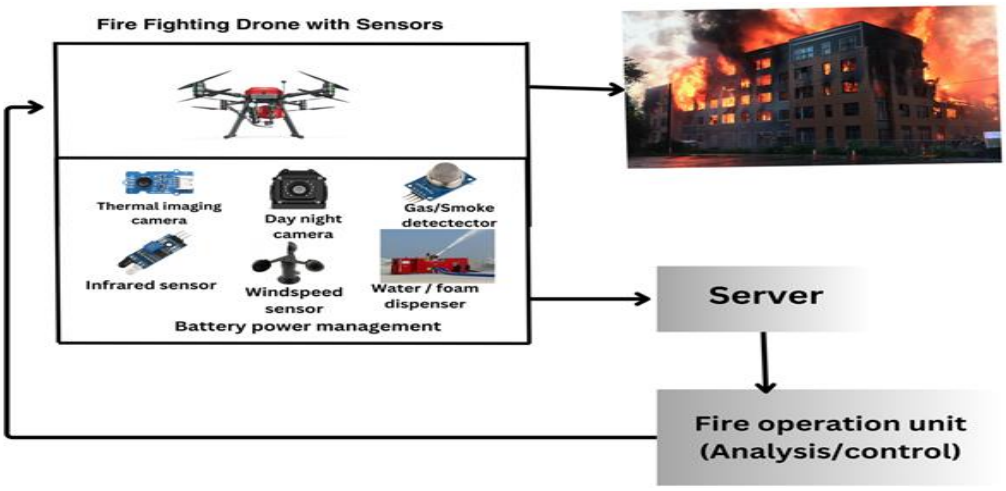

Figure 4. Strategies for deploying Drone technology

The drone enabled with different technologies and payloads such Thermal Imaging Cameras, Visible Light Cameras, Gas and Smoke Detectors, Infrared Sensors, Laser Scanners, Air Quality Sensors, GPS, Wind Speed and Direction Sensors, Water and Foam Deployment Sensors, Power Management Sensors. These sensors work in concert to provide a comprehensive understanding of the firefighting situation, enabling drones to assist firefighters in critical ways, such as identifying the fire's location, tracking its movement, assessing risks, and even delivering firefighting agents precisely where needed. After a successful inspection by these sensors, the drone will be deployed from the station to carry out its task of fire extinguish liquid

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spraying and release the fireball. These sensors have the capacity to identify fires and use the Internet of Things to transmit stress signals over the cloud. After receiving the stress signal, the Fire Control Unit (FCU) can determine the size of the fire and if the drone can finish its mission. The fire extinguishers liquid spraying nozzle connected from the tank, as per the detected sensor data the nozzle will deliver the fire extinguishers liquid to the appropriate GPS data. The same manner, the fireball is loaded and deliver to the appropriate GPS data based on requirement again and again.

An IoT system's principal fire suppression tool is high-pressure liquid fire extinguisher equipment. The apparatus consists of many parts, including a spray cannon, pressure pump, high-pressure piping, automated targeting servo mechanism, and tank for fire-extinguishing substance. This system is noteworthy since it can operate at up to 12 bars of pressure. The system uses two different kinds of high-efficiency fire extinguishing chemicals. including high-efficiency water-based fire extinguishing chemical and ultrafine dry powder. The fireball firing mechanism is a secondary instrument for applying fire suppression tactics when interacting with an IoT system. Among its components are a firing system, launching device, trajectory alignment mechanism, and fireball container. The fact that this device can accurately provide projectile power sufficient to propel fireballs is remarkable. There are six balls with a carrying capacity in the Fireball cartridge. The tethered firefighting drone With its 1,000 Watt continuous power, it can fly continuously at 60 meters in conditions ranging from -20 to +50 degrees Celsius. Additionally, it enables the operator to swiftly transition between confined and free flying modes.

The fire is still there. The same procedure will be utilized with a different drone to put out the fire. This process will continue until the fire is totally put out. Since no person is directly involved in the extinguishing process, the suggested technique would not only put out the fire but also save lives. A non-living object called a drone does all of the work in the fire, and should an emergency arise, the drone will instantly return to its starting location. The primary driving force behind multi-reason aerial automatons, often known as unmanned aerial vehicles (UAVs). It is done to reduce the risk of damage or fatalities as a result of putting out flames and inspecting scaffolds. Labor may be reduced by implementing a workable solution for building a UAV to put out fires and measure spans. This would improve welfare and lower the risk of accidents and deaths associated with these tasks.

Performance evaluation

During the performance evaluation, rigorous testing was conducted on both the hardware and software components to determine their operation in the drone and spraying and firing mechanism. The results of these functionality tests are included in Table 1. Based on the study, it was concluded that the mean passing rate is 99%. This insight clarifies the challenge encountered in effectively aiming and firing when the drone is in flight.

Table 1. Trials of system functional ability monitoring

S.No	Functions/Tasks	Passed Trials	Failed Trials
1	Flight at 120 Meters High and or Above	5	0
2	Ability Validation of Shooting Mechanism	5	0
3	Ability Validation of Spraying Mechanism	5	0
4	Flight Test While Shooting	5	0
5	Flight Test While Spraying	5	0
6	GPS System	3	0
7	Thermal Imaging Cameras	3	0
8	Visible Light Cameras	3	0
9	Gas and Smoke Detectors and Air Quality Sensors	4	0
10	Wind Speed and Direction Sensors	4	0
11	Water and Foam Deployment Sensors	5	0
12	Power Management Sensors	3	0

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Table 2 displays the documented firing and spraying distances accomplished by the UAV. The battery's lifespan on the ground surpassed its duration in flight owing to the components requiring full power from the battery.

Table 2. Shooting and Spraying test in Flight operations

S. No	Mode of Operation	Drone Flying Altitude	The distance from a target to the drone		
			Trial 1	Trial 2	Trail 3
1	Shooting test while flying	32m	4 m	3.5 m	3 m
2	Shooting test while flying	45m	4 m	3.5 m	3 m
3	Spraying test while flying	32m	3.5 m	3 m	2.5 m
4	Spraying test while flying	45m	3.5 m	3 m	2.5 m

Figure 4 illustrates the real photographs of the prototype taken during the functioning testing in different flying mode.

The 2.4 GHz remote controller is used to operate the UAV's movement, spraying, and shooting capabilities. A GPS module and gyroscope are included into the device to guarantee steady flying. The UAV achieved an astounding 99.9% success rate overall in this experiment, which tested its hardware and the effectiveness of its firing and dropping systems during flight. The UAV's weather-related sensitivity, which affects the precision of its shooting and spraying towards the target, was one significant obstacle faced throughout the test. As such, the controller of the UAV has to be taken over by a skilled operator. Furthermore, these balls with fire extinguishers are made especially to help with firefighting difficulties in smart cities.

The effectiveness of the fire extinguishing system has been shown by the spray distance of the high-pressure liquid fire extinguishing equipment and the spraying liquid of the pressure fire extinguishing equipment. With this technology, fire extinguisher is carried by drones and sprayed and dropped at the appropriate spot to ensure seamless and effective operation. In addition to having internet access, the drone should be using GPS to continually update its position.

Strategies for Fighting Fires

Strategies in firefighting it's includes single drone firefighting and multi drone firefighting. In single drone firefighting, Pressure dry powder fire extinguisher equipment may be chosen based on the fire site's conditions in order to rapidly suppress and put out the flames. High-pressure liquid fire extinguishing equipment may be utilized for continuous and uninterrupted firefighting in bigger flames, fires spanning numerous rooms, or fires in the outside insulation layer. In multi drone firefighting, It takes two or more drones to battle a fire simultaneously while using this fire strategy. Under one leadership, they ought to conduct a coordinated multi-unit action. Four forms of drone operations are as follows: partition operation, subregion operation, cross operation, and combination of both. It was discovered that the drone worked very well in putting out flames in a variety of settings. Fires of all shapes and sizes might be swiftly put out by the drone. Unmanned aerial vehicles (UAVs) fitted with fire-fighting tools, such water, foam, or extinguishing balls, are known as firefighting drones. Usually, controlled environments are used to test these

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drones' fire-extinguishing efficacy in order to determine how well and safely they can put out flames.

4. Conclusion

The number of fire incidents has increased recently, resulting in decades' worth of significant property damage as well as the deaths of several people. A smart solution has been proposed to solve this problem, intending to minimize both the time needed to extinguish flames and the loss of life. Unmanned Air Vehicles have emerged as a viable aspect in averting such disastrous occurrences. This unmanned aerial vehicle has an innovative design that enables it to shoot and spray fire-resistant balls and liquids. This approach merges IoT technologies and Cloud computing with Drone equipped to carry fire extinguisher liquid and balls. By applying this technique, the efforts made by firefighters are minimized, and it assures the conservation of water resources, vital since enormous quantities are often squandered during fire events. The integration of this technology is set to alter the globe and maybe limit the frequency of fire accidents globally.

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