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Drones in Disaster Response: Real-Time Data Collection and Analysis

Mugisha Emmanuel K.

Faculty of Science and Technology Kampala International University Uganda

ABSTRACT

In recent years, drones have emerged as critical tools in disaster response due to their rapid deployment, real-time data acquisition capabilities, and ability to access hazardous or inaccessible areas. This paper examines the evolution and deployment of drone technology in disaster scenarios, highlighting their role in collecting and analyzing real-time data to assess structural damage, locate victims, and support rescue operations. Various types of drones, including quadcopters and ground-based systems, are examined for their efficiency in different disaster contexts. The integration of technologies such as thermal imaging, 3D mapping, and automated victim detection significantly enhances situational awareness and response speed. Case studies from past disasters, such as earthquakes and hurricanes, demonstrate practical applications and outcomes. Challenges such as data processing bottlenecks, logistic limitations, regulatory gaps, and ethical concerns, including privacy and data sensitivity, are critically analyzed. The study also outlines emerging trends, including autonomous decision-making, hydrogen-powered drones, and enhanced collaborative mapping systems. This research contributes to the discourse on how drone technology can be optimized for disaster resilience while maintaining ethical integrity.

Keywords: Drones, Disaster Response, Real-Time Data, Unmanned Aerial Vehicles (UAVs), Victim Detection, 3D Mapping, Ethical Considerations.

INTRODUCTION

Disaster events are devastating occurrences that destroy the environment, devastate buildings, displace families from homes, debilitate entire communities, and ultimately cost human lives. Recent unfortunate events have highlighted the need for rapid intelligence gathering in disasters of all kinds. This need arises because a quick assessment of the damage is required to identify the areas most affected and to allocate resources to those areas. In such environments, a large number of poor-quality aerial images, along with some DTM, may often be the only available aerial data source. In addition, an aerial survey by remotely piloted aircraft systems (RPAS) with cameras can provide informative visual indications of casualties. It is, therefore, vital to understand and analyze the images immediately in a disaster situation. Meanwhile, the multi-robot approach significantly improves the detection accuracy and robustness of the system. The proposed robotic system is cost-effective and scalable, as a suitable aerial component can be attached to any off-the-shelf drone. The overall collaborative system developed has been tested to ensure each segment works individually as well as in conjunction, and has been demonstrated with six different real-life casualty detection scenarios. Further development will look into improving the casualty detection algorithm to operate with different victim styles, effects of camera angle, and a more advanced on-board processing unit. A better avidity metric may also be explored to evaluate the search path of the preexploration. This study addresses the estimation of human conditions using aerial images of drone images of a disaster. However, only the human class was targeted in this study. Meanwhile, several methods of human condition estimation are tested, and a small number of target candidates is detected in this study. A more sophisticated method using a combination of these methods can be the future idea [1, 2].

History of Drone Technology

The first drone, the Kettering Bug, was first flown in the United States in 1915, as an early cruise missile designed for use in World War I. It was fueled by internal combustion engines and could fly just a bit over seventy-five miles before crashing to the ground. It was designed by Charles Kettering, who applied for and received a patent for it. Although it was never used in wartime, its designs have been provided to later drones, including the Army's Pegasus drone. In reality, it was an unmanned aerial vehicle that lacked a control mechanism. Drones, or unmanned aerial vehicles (UAVs), are in many ways the offspring of the Kettering Bug. In the last five years of the last millennium, interest in these vehicles switched from military applications to commercial uses. The second big drone wave started on September 11, 2001, following the terrorist attacks in the United States. The demand for drones soared, as research and development of UAVs, as many demand them for a variety of applications ranging from border patrol to agriculture. Interest in the technology remained high as UAVs were employed in Iraq and Afghanistan for surveillance and precision bombing. In fact, from 2005 to 2015, United States drones killed an estimated 4,000 individuals in Pakistan, Yemen, and Somalia, giving birth to the trope of drone-ridden invisibility. Many believed that UAVs would be able to solve problems from famine to climate change, rendering bored graduates of top engineering schools to a life of opening letters from patent-granting inspectors and doing only spot checking. In contrast, some analysts warned that they were toys out of control, leading to unforeseeable catastrophes due to misuse or hacking, or ubiquitous monitoring and invasion of privacy [3, 4].

Types of Drones Used in Disaster Scenarios

When disasters strike, drones play an essential role in damage assessments. This section explores their usage and effectiveness, comparing types used in disaster situations, particularly focusing on quadcopters and ground robots. Timing and quality information are critical, as studies show how these robots can explore and report environmental metrics in real-time. The Automated Aerial Robot Controller (AARC) builds a 3D map while providing live video, and ground robots autonomously assess environmental stability. Airborne drones cover large areas quickly, offering a broad overview, while ground robots focus on detailed evaluations of smaller zones requiring assistance. This hybrid system facilitates quick and accurate evaluations once robots are deployed, providing substantial visual and quantitative data in post-disaster scenarios. A bird's-eye view yields efficient coverage, tracking people's locations effectively. The 'Search and Rescue' (SR) localization method enhances scanning efficiency, reducing travel distance by up to 45% compared to traditional methods. Drones prioritize human presence rather than structures, categorizing conditions into 'safety,' 'unrisked,' and 'risked' classes. Understanding underground conditions is crucial, especially when infrastructure is compromised and people may be trapped. Drones enable quick comprehension of disaster sites through rapid search capabilities [5, 6].

Advantages of Using Drones in Disaster Response

Drones offer real-time data during disasters, yet their mapping and algorithms remain suboptimal. A drone app maps the area, reads private lists, and generates a control list. Drones dynamically estimate and track new positions, streaming original video for local assessment without extra labor. Demonstrations of low-cost drones show their potential. Natural disasters like tsunamis and floods necessitate rapid information gathering for resource allocation, but communication often falters. Proper land mapping is crucial for effective disaster response. Traditionally, bulk personnel and vehicles are sent to gather information, consuming time and resources. Now, Unmanned Aerial Vehicles (UAVs), or drones, scout terrain and relay data efficiently. Earlier systems required costly equipment and were limited to victim searches, needing new drones for mapping after detecting areas of interest. These earlier models lacked video feeds essential for rescue operations. The proposed system integrates drones and ground robots utilizing low-cost models in a collaborative environment, enabling dynamic map exploration. A 3D feature-based map is created via a camera-equipped drone, with collaboration from a quadrotor, storing data in an existing map and sending information on high vulnerability areas based on priority lists [7, 8].

Real-Time Data Collection Techniques

After a disaster, it is essential to acquire a basic understanding of the impact of infrastructure damage. It is also important to grasp the situation of the victims promptly, that is, as accurately as possible, to rapidly respond to the on-site situation. Under the situation, the view from the air is more advantageous than that from the ground, since it is possible to understand a broader area and can capture the situation with an overall picture. However, a helicopter is costly and is not realistic for wide-range reconnaissance. In addition, fixed-wing aircraft cannot provide a detailed examination of the situation at the disaster site. Thus, police and fire departments, as well as news media organizations, have used drones as a means of gathering information about disasters. After a disaster, understanding the damage is conducted by gathering information on the proper understanding of location and state of the disaster. In the case of the damage caused by the 2011 Great East Japan Earthquake off the Pacific coast, the situation could only be grasped with a fair interval of hours for general buildings. On the other hand, with drones, images of surveying a wider area than with manned aircraft can be obtained in a short time, and an accurate image of the buildings can be obtained even in a building with a larger number of stacked structures. Furthermore, drones can easily provide an overall understanding of geographically dispersed areas. Information obtained by drones is mainly aerial image data; thus, it is possible to understand the disaster site by image processing. The simplest method was report sort out reports by aerial images into farmland and non-farmland, and input this information into Google Earth. There are two types of damaged buildings modeled by computer vision, such as 3D modeling of the Tsunami impact in Taro-cho town in Iwate, and damage levels classification by monitoring missing roofs in Kobe. However, image processing cannot be applied to all damages. One of the advantages of drones is that the sensors can be changed depending on the different types of disasters [9, 10].

Data Analysis Methods

Whether man-made or natural, disasters such as earthquakes, tsunamis, and landslides can cause severe damage to people, buildings, and structures. In particular, assessing the damage situation soon after a disaster occurs is essential for prompt rescue operations that need a large number of rescuers and resources. After an accident or disaster, first-aid medical assistance is an important issue. In many recent large-scale disasters, aerial images taken by drones have been effective in understanding disaster sites. Drones are useful for understanding a disaster site because they can quickly search a wide area that human rescuers take a long time to visit. Drones can gather image information from a bird's-eye view and acquire images of damaged buildings and streets obscured by debris and blocked by fallen buildings and structures. Drone images can fly in a dangerous area that is inaccessible to humans due to gas leaks or other health risks. On the other hand, assessing the conditions of victims and rescuers is also important to save lives. For example, it is necessary to assess the number of victims or rescuers missing maintained, requiring the deductions of their condition from the drone images. The condition includes whether or not there are victims and rescuers, whether they are saved or not, and whether they are alive or not. Therefore, in the analysis of drone images, it is very important to respond to the understanding of human conditions. This paper studies the estimation of conditions of people in disaster sites from an aerial viewpoint. Understanding the conditions of people requires various sensors and lenses capable of acquiring the skin color information of the searched people. However, many drones mounted with cameras can only acquire aerial images of a large area from an overhead view. It is difficult for humans to pay attention to the rescuer or victim in an aerial image to understand human conditions [11, 12].

Case Studies of Drones in Action

Drones have become essential in disaster response for rapid damage assessment, victim detection, and real-time data collection. This study showcases researchers using drones alongside RGB live feeds, thermal sensing, and laser scanning for 3D reconstruction. The technology's application involves assigning missions to aerial and ground robots. Quick assessment of damage is vital for resource allocation, with aerial robots exploring affected areas and ground robots providing inspection and assistance. Collaborative mechanisms enhance overall capability. The aerial vehicle maps the environment in 3D, creating a real-time bird's eye view displayed at the ground control station. Here, vulnerability assessments are computed, directing the ground robot autonomously to critical locations. This method has been tested through simulations and some real trials with an actual aerial vehicle and ground robot, illustrating effective communication and environmental mapping. While UAVs are widely used in military and commercial sectors, their application in disaster management has gained research interest. Drones provide detailed, real-time information on disasters, including high-resolution RGB and thermal images for victim localization. However, analyzing these data can be challenging. The case study outlines a practical method for victim identification using data residuals, noting that further processing methods are required as residue images alone are insufficient. The presented method aims to deliver results quickly, functioning adequately in situations where uniform movement can aid in victim recognition, although safety planning is essential to avoid fatal consequences [13, 14].

Challenges in Drone Deployment

Drones efficiently survey disaster zones faster than humans or vehicles, yet encounter challenges like logistics and data processing limitations. This paper proposes enhancing collaborative exploration and mapping, allowing drones like Amazon Prime delivery models to conduct reconnaissance. The drones will gather point cloud data to create detailed 3D maps and relay camera data back to ground control for evaluation. Additionally, a cost-effective drone add-on for victim detection is suggested, which can function independently or enhance existing systems. Scalability and versatility are crucial for effective deployment in rescue operations. This study examines how drones were utilized post-2017 hurricanes in Florida and Texas for assessing flooding, roof damage, and outages. Although drones provided valuable data, the exchange of aerial information with decision-makers faced challenges. Rapid impact assessment models were less effective, with key data on critical infrastructure like bridges and highways being prioritized. Infrastructure owners often delay drone deployment compared to aerial service providers and local governments. The author emphasizes the lessons from 2017 regarding the importance of innovation in tool deployment and the factor of speed. Discussions following Hurricane Sandy touched on drones, training, and data sharing, but these concepts remain unintegrated, risking misuse by poorly trained personnel and leading to complications and information loss during responses [15, 16].

Future Trends in Drone Technology

In disaster situations, drones have a wide range of applications; however, their use in this area is not as widespread as it could be. Some trends in the future use of drones for disaster management are green/sustainability, automated reporting, safety, flexibility of operation, and miniaturization of drones and their components. The use of hydrogen-powered drones is one way to increase the flight time of drones and allow them to reduce the amount of carbon monoxide emitted. It is possible to allow companies the ability to opt for drones with hydrogen cells instead of battery-powered or traditional combustion engines as an alternative when they are in the market for new drones. For this to happen, several challenges regarding the safety and airworthiness of hydrogen-powered drones involved would first have to be examined and mitigated as far as possible in a way that is accepted by the aviation authorities. In the case of drones that are used for surveying purposes, a new trend would be automated reports based on the collected data. For instance, automated 3D visualizations of buildings that were surveyed and color-ortho photos could be generated by using collected images as input. This would allow for usage in other software or presentations directly in the drone's software. This is particularly useful for providing overviews of the state of the buildings or for reporting purposes in a more understandable way than numbers and polygons. Safety with drones is currently a safety trend for ensuring safety. In terms of air traffic safety, this means avoiding any conflicts with manned aircraft. Regulations guide this process, which most companies should adhere to since they are the non-exceptional rule. However, the lack of air traffic control or any automatic warning systems makes the 600-foot range questionable, especially in the interest of the safety of manned and unmanned flights. To promote its usage in disaster scenarios, one way to increase the safety of all drone flights is to include some form of air traffic control. The flexibility of operation allows drones to be used in confined spaces and scenarios with safety [17, 18].

Ethical Considerations in Drone Use

Ethical considerations for UAVs in disaster response share commonalities with other UAV applications but also have unique aspects. Key ethical issues include accountability, transparency, privacy, oversight, autonomy, and functionality, specifically focused on Collection and Dissemination. This section explores these ethical challenges for UAVs, emphasizing the need for guidelines to prevent ethical missteps. UAV-collected data may contain sensitive information revealing personal details, thus requiring careful handling to protect privacy. An ethics of secrecy perspective suggests that such data should not be shared carelessly. Understanding when UAV data becomes sensitive involves assessing several dimensions in

UAV design and usage. The concept of geoprivacy highlights the potential for UAV data to infringe on privacy zones, particularly if data reveals significant private locations without consent. Applications in law enforcement, military, and surveillance often breach reasonable expectations of privacy, raising ethical concerns. Disaster response data collection faces different ethical dilemmas than traditional tech applications. An ongoing ethics project aims to clarify considerations for UAV pilots and their organizations. Key questions include knowledge of population density, feedback mechanisms, and the future use of collected data for research. Addressing policy, oversight, and ethical inquiries is essential for UAV developers and operators, particularly regarding automation and its influence on policy formulation [19, 20].

Training and Certification for Drone Operators

The rapid deployment of Unmanned Aerial Vehicles (UAVs) for disaster response necessitates standardized training and certification programs to enable timely and effective UAV utilization. Commercial pilot licenses and drone operator certificates consist of both written and flight tests, but this certification system does not serve the need for timely and effective UAV utilization. Deployment within a few hours after an accident or disaster would be lost if the UAV operation used this certification. Furthermore, it is impractical to conduct regular training and an evaluation until an accident becomes unavoidable. Therefore, this research proposes a new training and certification system consisting of an online written test and flight simulation tests. When an application to use a UAV is received, the required certification is determined based on accident prediction by simulating the potential severity and area of the accident using physical modeling. Next, the operator is dispatched to the destination to conduct a written test. The question is selected from a pool consisting of multiple-choice questions, short-answer questions, and so on, and the database is created concerning the applicable UAV type. The validity of this testing system was confirmed, and its effectiveness was demonstrated. To verify UAV operation, a flight simulation using a low-cost commercial drone was developed. This flight simulation was designed to evaluate the UAV flying skills and to visually check the proficiency of the UAV pilots. This paper discusses a new approach to UAV operator training and certification to improve the rapid deployment of UAVs in disaster response. The proposed system was briefly explained, and the contribution of the new training and certification system was shown. In future work, to systematically evaluate the contribution of the system, a numerical model of the certification system and evaluation of operator training and certification will be conducted. Furthermore, a simulation-based training and certification system will be implemented into a practical training system [21, 22].

Collaboration with Emergency Services

As UAVs integrate into humanitarian missions for natural disasters, appropriate usage is crucial. Initially viewed as a transformative technology, excitement was quickly overshadowed by skepticism related to regulation, privacy, and feasibility, especially in developing nations. Their adoption represents both innovation and a new approach to disaster response, highlighting the balance between acceptance and skepticism. The expanding access to aerial imagery greatly boosts demand for UAV services. Unlike satellites, UAVs offer real-time imagery for damage assessment, enabling NGOs and organizations to gather timely information. Most UAV efforts have been in the Global North, but acceptance by local NGOs, governments, and international aid organizations is vital. Countries like Haiti, Nepal, and the Philippines show significant local drone use. Skepticism often arises from fears of state intrusion, leading to either blanket bans or inconsistent frameworks for UAVs. Even in unregulated regions, negotiations about airspace rights occur, as seen with Sri Lanka's Department of Civil Aviation [23, 24].

Public Awareness and Education

Information on disaster preparedness, early responses, and education on how to operate drones can be broadcast to the directors of both external organizations for disaster response and citizens in disaster-affected regions. The educational content can include familiarization with operating methods, capability characteristics, and safety measures of using drones. While drone operation training and lessons can be recorded, residents of affected areas can be educated on how to maneuver with drones to conduct field inspections and verify damage reports. As knowledge about drones spreads to other organizations related to disaster responses, drone-based assistance technology can be integrated into task forces. Organizations collaborating in disaster responses can benefit through education on how to operate drones and what kind of information can be collected through drone operations. These knowledge-sharing sessions can be held before disasters occur so that appropriate tasks and methods can be planned before a disaster. To prepare for firefighting efforts, law enforcement agencies and fire departments can hold joint drills that involve collecting and sharing drone footage in the vicinity of a target fire so that the agencies can be aware of how drone-based inspections can be used in firefighting. Further, evacuation drills can be performed to transfer drone operation skills between organizations. Furthermore, it should be discussed beforehand about roles in and methods of capturing information when waves of emergency response-related requests to operate drones flood in from regions afflicted by a major disaster. In the case of natural disasters, the most appropriate government organization executes disaster response activities. In Japan, meteorological observation and prediction are usually conducted by the Japan Meteorological Agency. In contrast, in the United States, 50 states observe weather conditions through around 3,600 automated weather stations, and 157 local offices of the National Weather Service predict disasters [25, 26].

Funding and Resource Allocation

A major challenge for the implementation of disaster response drone systems is obtaining funding and resource allocation. Missed funding opportunities can be an especially impactful barrier to more extensive and proactive drone integration in an organization's disaster response program. Consequently, recommendations for funding strategies and grants are included. These strategies are intended to supplement the guidance already provided on building capacity to address the questions of Where are drones needed? and when should they be deployed?. A more thorough list of funding opportunities can be found in. Seek to obtain early-stage funding through internal grants or outreach to departments and groups within the organization that may be interested in using drones for other purposes. To build a more formal and long-term sustainability plan, a similar organizational approach can be taken to secure mid-level general operating grants, such as those available from. Various government procurement programs can also complement grants. Commercial grant foundations such as sometimes undertake focused grant programs after disasters, particularly involving technology. Organizations might consider creating a small-scale prototype project through other funding opportunities, such as before pursuing larger, comprehensive funding sources. For example, public safety drone implementation suites could be detailed through extended partnerships with local drone manufacturers, allowing communities to brainstorm and build off of initial solution designs. Attainable prototypes could then be built, and with testing, efforts could be made to scale drone use and community readiness for larger future funding opportunities. A financial consortium of interested communities could also be considered if many communities have ready-built pieces. Another critical barrier to collaboration has been routing issues. Many organizations have limited collaboration with unreserved scheduling resources like UASs or draining shared resources across many at the same time. Organizations with well-established systems and processes like UASs tend to prefer keeping them in-house. Overall, setting the groundwork for success in grant writing and securing funding opportunities is vital for the longevity and further integration of this technology [27, 28].

International Perspectives on Drone Use

Various countries have integrated drone technology into their emergency services. This paper shares the authors' experiences with drone-based data collection internationally. It highlights the evolution of drone use during different incidents, focusing on their involvement following the 2011 Great East Japan earthquake and tsunami. In March 2011, based in Canada, the authors began investigating the disaster. At the request of Japanese colleagues, drone flights over ground zero took place about four months later, aiming to use aerial imagery for assessing human costs and supporting policy recommendations. On July 28, 2011, with a production crew from Dai Nagoya TV and a local photographer, an initial flight was performed using a Draganflyer X4-ES drone to capture images of the Fukushima Daiichi Nuclear Power Plant. These exploratory flights demonstrated UAVs' potential as remote sensing platforms, establishing methods for transmitting high-resolution imagery via wireless internet during flights. A mini-UAV from a local supplier and several GoPro cameras were later acquired for further flights. Initial efforts focused on finding software to synchronize and geo-reference UAV-captured images. In April 2011, the authors visited Japan to document UAV effectiveness in the early ODA work by the Japanese Self-Defence Forces and the Japanese Red Cross. They visited Tōhoku Gakuin University in Sendai and NPOs involved in recovery, but translation issues hindered dialogue. Despite these challenges, the March 2011 disaster's effects remained relevant for pamphlets for Tōhoku visits. Cross-national discussions with UAV planners achieved modest successes, including certified drone pilot operations with local teams and media exposure. However, complex UAV regulations were noted, limiting initial flights to data collection for panicking datasets or hydrographic modeling of river valleys [29, 30].

CONCLUSION

Drones have revolutionized disaster response by enabling rapid, accurate, and safe assessment of disaster zones. Their ability to collect and process real-time data allows first responders to make informed decisions, allocate resources efficiently, and potentially save lives. Through integration with ground robots, thermal sensors, and advanced mapping algorithms, drones provide comprehensive situational awareness even in complex and hazardous environments. However, maximizing the benefits of drone deployment necessitates addressing several challenges, including data interpretation, logistical coordination, regulatory compliance, and ethical concerns such as privacy and surveillance. Future developments in drone technology, such as autonomous navigation, hydrogen propulsion, and real-time automated reporting, hold promise for even more efficient and sustainable disaster response systems. To fully realize the potential of drones, collaboration among technologists, policymakers, and humanitarian responders is essential, ensuring that innovation aligns with ethical and operational best practices in emergency scenarios.

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