Drones for Civil Defense: A Case Study in the City of Niterói

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Keywords: Drones, Unmanned Aerial Vehicle, Smart Cities, Civil Defense.

Abstract: Nowadays, *drones* or *Unmanned Aerial Vehicles* (UAVs) are employed for several purposes such as delivering products, spreading pesticides on crops, providing internet access to remote areas, and taking videos and photos for entertainment. In the context of smart cities it is not different. Some cities have adopted drones for a number of important tasks, such as surveillance, traffic monitoring, and disaster management. Indeed, their ability of reaching difficult places and the possibility of carrying different sensors and actuators make those devices very flexible tools that can adapt to several use cases. Nevertheless, there are still obstacles — technical, regulatory or even social — that can hinder the applicability of drones to certain tasks. In this work, we report and analyze the use of drones by the Civil Defense Office of the city of Niterói, Brazil, as a case study. In recent years, the office has been increasingly adopting drones for automatizing or simplifying a number of processes with varying degrees of success, and intend to adopt information and knowledge management systems to support and optimize their use. We present a list of the current drone-aided tasks performed by the office, as well some potential applications that are not yet feasible for one reason or another. We further analyze those obstacles and discuss what can be done to address them.

1 INTRODUCTION

Popularly known as *drones*, Unmanned Aerial Vehicles (UAVs) are flying devices that can be used for a variety of purposes due to their mobility and ability to collect data from a region of flight. Either autonomously or controlled by a pilot, drones can carry out remote missions replacing the human presence, which can either enable activities that were otherwise impossible — *e.g.*, due to the impossibility of reaching a certain region of interest — or, at least, minimize risks and accelerate the delivery of services and goods. For a few examples, drones have been used for monitoring volcanic environments (de Moor et al., 2019) and, famously, by the Amazon prime air service (Shavarani et al., 2018).

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Those two examples help illustrate the wide range of activities that can be enabled or aided by the use of drones. This flexibility can be explained by three particular characteristics of these devices: their ability to fly — thus allowing highly efficient and effective mobility —, as well as their capacity of carrying different types of loads and their intrinsic communication functionalities. More specifically, drones can carry both sensors and actuators which can be accessed remotely using the drone's communication channel with the ground station. While recreational drones often carry cameras for video or photography, other types of payload can be added, such as smoke detectors, temperature sensors, speakers, or headlights. Therefore, armed with the right payload, drones can be adapted to countless activities. This has popularized their usage in several different fields, including agriculture, entertainment, industry, military, surveillance, maritime rescue and security in-

Bastos, C., Passos, D., Barbosa, W., Felipe, Y., Loureiro, T., Dias, G. and Passos, F.
Drones for Civil Defense: A Case Study in the City of Niterói.
DOI: 10.5220/0011552800003335
In *Proceedings of the 14th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management (IC3K 2022) - Volume 3: KMIS*, pages 72-82
ISBN: 978-989-758-614-9; ISSN: 2184-3228

spection of construction sites (Hassanalian and Abdelkefi, 2017; Ayamga et al., 2021).

In the context of smart cities, drone usages may be roughly divided into three broad categories: monitoring (*i.e.*, gathering data by means of certain types of sensors), actuation (*i.e.*, performing actions onto the environment) and services (*i.e.*, serving as a complimentary infrastructure). As examples, UAVs can be used for monitoring traffic and pollution, detecting accidents and wildfire, improving communication network connectivity, and assisting city surveillance structures (Alsamhi et al., 2019; Kim et al., 2018).

While the aforementioned activities are common for most cities around the world, each region has its own set of particular issues. Niterói is a Brazilian city of about 500 thousand inhabitants — a medium-sized city by Brazilian standards —, located in the metropolitan region of the state of Rio de Janeiro. It is considered an ongoing smart city, with initiatives currently under implementation through the *Applied Projects Development Program* (PDPA) (Reis et al., 2021), a partnership between the City Hall and Universidade Federal Fluminense (UFF).

Even before the PDPA, the City Hall of Niterói already used drones for a number of purposes. More specifically, in recent years, its Civil Defense Office has been using drones in some of the services it provides to the local population. Indeed, the expertise developed by Niterói's Civil Defense in the usage of drones for the well-being of the population has become a reference in Brazil, and its teams are often deployed to help disaster-response missions around the country, as we will detail in the rest of this paper. Aside from those disaster-response missions, this office also provides efforts to prevent and protect the citizens from natural hazards, as floods, landslides and wildfires. In a nutshell, it works with both routine and emergency operations in order to prevent, mitigate, evacuate and/or recover from disasters. In that sense, drones are used to inspect regions — either where a disaster has taken place or that have a potential for a natural disaster —, seeking to capture information that will help carry out rescue operations and avoid further damage.

This work is one of the first results of DroNit, one of the PDPA projects, which aims to optimize the use of drones in the Civil Defense Office by applying, among other techniques, information and knowledge management. The paper has the specific objective of reporting the practical experience of Niterói's Civil Defense Office on the use of drones. Other aspects will be the subject of further work. We list and describe a number of current drone-aided activities performed by the office, discussing how the drones have enabled them or made them more effective. We also highlight limitations of the currently used drones for those tasks, pointing out the technical challenges that hinder a more effective applicability. We further describe other activities of the Civil Defense that could perhaps be aided by drones, but that currently not possible either for technical, regulatory or even social reasons.

The contribution of the paper is multifold. Firstly, it raises awareness for innovative uses of drones that are possibly useful for other cities. Secondly, it highlights gaps in the current drone technology that hinder its usability for useful smart city applications. Thirdly, it indicates possible research areas and open problems regarding the usage of drones in smart cities.

The remainder of the text is organized as follows. Section 2 reviews a number of common uses for drones in smart cities and provides a brief overview of the related literature. Section 3 presents our case study of Niterói's Civil Defense Office, describing its typical tasks that are — or could be — aided by drones. In Section 4 we highlight the main challenges identified with the usage of drones for the activities of the office and also discuss ideas for how the drones' usefulness my be improved for the Civil Defense. Finally, Section 5 concludes the paper.

2 DRONES FOR SMART CITIES AND CIVIL DEFENSE

Jensen (Jensen, 2016) addresses the theme of drones and their potential applications in the area of smart cities. In his work, he explores the connectivity issues related to the use of drones in smart cities and discusses how drones can improve their applications such as surveillance, object detection, general purpose distributed processing applications, data collection, route planning, tracking delivery, navigation and collision prediction.

The implementation of a service based on the use of drones requires studies in several aspects (Alsamhi et al., 2019). One of them is to establish a physical architecture, that is, choosing the drones, the types of connectivity available, the types of sensors and actuators, establishing ground stations for battery recharge, and establishing maximum flight time considering the measurements that will be performed. As an example, (Kim et al., 2018) designed a framework for the use of multiple UAVs to cover extensive areas for surveillance. The authors consider public and private UAVs — public institutions and companies or citizens, respectively — analyzing aspects such as battery limitation, delivery of supplies (*e.g.*, medicine), collision avoidance, global positioning, autonomous flights and connectivity using standard for vehicular communication (IEEE 802.11p) or over LTE (Long Term Evolution) when available in the region. Still in this context, (Katila et al., 2017) studies scenarios where drones are used to monitor a large area and transmit video information to a remote control unit using multiple hops. To maintain a strong connectivity between drones and the control unit, the authors used wireless mesh networks (IEEE 802.11s) at fixed positions on the ground to increase the node redundancy for routing.

Giordan *et al.* (Giordan et al., 2018) present a review of remotely piloted aircrafts (RPAs), also known as UAV, applied to natural hazards around the world such as landslides, floods, earthquakes, volcanic activity and wildfires. RPAs are used to collect data from inaccessible regions typically from images from conventional cameras, but also, in some cases, from thermal sensors and multi-spectral cameras. These RPA-gathered data are then georeferenced and processed in order to provide, for instance, environmental and geological studies, mapping different active processes at the Earth's surface and analysis of river channel vegetation.

More recently, Gohari *et al.* (Gohari et al., 2022) systematically reviewed the literature of using drones for monitoring and surveillance in smart cities, classifying the papers into seven categories: transportation, environment, infrastructure, object or people detection, disaster management, data collection and other. Air pollution (environment) and traffic monitoring (transportation) are the aspects more studied in the recent literature. In the disaster management category, the main areas are human body detection, evacuation map building, fire detection, firefighting management and search and rescue. They also associate the categories according to the number of UAVs (multiple or single), type of UAV (mostly, with rotatory wings) and the aerial sensors on board (mostly, conventional camera).

2.1 Characterization of Drones

Because drones are used for so many different applications, several different offerings can be found on the market with markedly different characteristics. Perhaps the most fundamental way drones may differ is in terms of typology, the most common being fixed-wing, single-rotor, multirotor, and fixed-wing hybrid (Jayaweera and Hanoun, 2020). Like an airplane, fixed-wing drones have rigid wings that provide lift whenever the aircraft moves forward. Conversely, single- and multirotor drones have rotating vertical propellers for lift. While fixed-wing drones can achieve much higher speeds, cover larger distances and potentially carry substantial weight, single- and multirotor drones have advantages in terms of maneuverability, allowing more controlled flights and the possibility of remaining at a relatively stable position (which often aids in tasks involving photography or video). In particular, multirotor drones are more stable than their single-rotor counterparts, and the number of propellers usually correlates with their load capacity (Hassanalian and Abdelkefi, 2017).

Drones also vary wildly in terms of weight and size. While consumer drones used for entertainment can weigh as little as a few hundred grams, military drones can weigh several hundred kilograms and be roughly as large as some manned aircraft (Hassanalian and Abdelkefi, 2017). Because heavier drones require more powerful propellers, they are also usually able to transport more load.

Another important issue is autonomy. Consumer drones in general use electrical engines powered by batteries which offer relatively short flight times. Some larger capacity drones, however, use internal combustion engines allowing for much larger autonomy.

While some drones may have a few autonomous flight capabilities (*e.g.*, avoiding collisions, returning home under certain conditions), the most common mode of operation has the drone being piloted remotely. Thus, a reliable communication between the drone and a ground station is fundamental. Different radio technologies can be found in different models. Some models resort to open standards, such as IEEE 802.11, while others may employ proprietary radio solutions — DJI, for example, uses its own radio technology called OcuSync (Swinney and Woods, 2021). However, regardless of the particular technology, consumer drones must generally operate under unlicensed radio bands, alongside multiple competing devices, which may reduce communication performance.

In terms of payload, consumer drones often carry ordinary cameras for visible light, which can be used both for aiding the pilot and for recording video or taking photos. For more specialized applications, multispectral cameras can be used — *e.g.*, infrared can be used for monitoring vegetation growth and coverage. Thermal cameras are also useful for finding lost persons, especially under vegetation coverage, such as in forests. Drones equipped with a LIDAR can map the topography of a region and/or of buildings. Other possibilities include sensors for temperature and smoke, which can be useful for detecting

Table 1: Main roles of the Civil Defense office of Niterói.

Id.	Role	Reactive	Proactive
1	Identify and map risk areas, monitor slope/hill stabilization works		✓
2	Inspect risk areas avoiding occupations		✓
3	Inspect buildings, evacuating areas of risk or vulnerable buildings		✓
4	Inform the population about risk areas, extreme events, protocols	✓	
5	Perform simulated exercises		✓
6	Collect, distribute and control supplies in disaster situations	✓	
7	Assess damages and losses of disaster affected areas	✓	
8	Develop citizen awareness of disaster prevention		✓
9	Encourage economic and production restructuring of affected areas	✓	
10	Train human resources for civil defense and protection actions		✓
11	Provide data and information to the national system	✓	

fires. Actuators can also be carried by drones. Headlights and loudspeakers, for example, can be used to draw attention to the drone or to disseminate warning messages. In agriculture, drones are often equipped with tanks that can store liquids for irrigation or application of pesticides. Those sensors and actuators can either be controlled by some standalone computational device — also carried by the drone — or be connected to the drone's flight controller so that they can be accessed remotely by the same communication channel used to pilot the vehicle.

3 CASE STUDY: CIVIL DEFENSE OF NITERÓI

In this section, we describe the main activities of the Civil Defense Office of the Niterói City Hall and how those activities are — or could be — aided by Drones. The information contained here is based on several interviews we conducted with the personnel of the office, as part of a process of understanding their needs, as well as how their current experience with drones is and what could be improved.

3.1 Roles and Daily Activities

The mission of the Civil Defense Office is regulated by a municipal law[1] which defines the assignments of the civil defense and protection services to the citizens of the city of Niterói.

The overall goal of a Civil Defense office is to protect the population against natural disasters, as well as other types of civil disturbance. This is done both reactively — *i.e.*, in response to particular occurrence — and, ideally, proactively — *i.e.*, by taking measures that avoid or mitigate the occurrence of such events. Table 1 presents the main roles of the office and their classifications in relation to being reactive or proactive to disaster events.

This is, of course, a broad definition and, as such, can encompass different concrete actions for offices of different cities. Aspects such as the city's climate and topography, as well as cultural trends of the population itself, play an important role on defining the responsibilities and specific daily actions of a particular Civil Defense office.

Niterói, in particular, is a coastal city with tropical climate. Temperatures are high through most of the year, and heavy rains and storms are frequent during the summer. The topography is quite uneven, formed by hills spread throughout the city area. Due to this topography and to the population density, houses and other types of constructions are often built on those hills.

Unfortunately, the combination of those factors makes mudslides a common and troubling occurrence. Those mudslides can destroy houses and lead to deaths. That is especially likely for illegal constructions, such as houses built on unstable terrains and without the proper permits demanded by the city hall. Thus, this is an area of particular concern to the Civil Defense Office.

In order to avoid or mitigate tragedies related to those mudslides, the office has to constantly monitor the city perimeter for early signs of illegal constructions. It also has to monitor areas that are particularly vulnerable to this type of event, such as hills, checking the state of vegetation coverage, as well as signs of terrain instability.

One of the tools employed by the office for this purpose are satellite images. Those images are received periodically and are analyzed by technicians. The goal is to identify and measure areas of deforestation, as well as possibly illegal constructions.

[1] Law nº 3561 published on December 18, 2020, available (in Portuguese) in http://leismunicipa.is/dvfyk.

Nevertheless, despite those preventive measures, mudslides sometimes still occur. When they do, the Civil Defense office is also responsible for emergency actions, such as assessing damage, helping evacuate the affected area, helping find survivors, as well as making essential supplies arrive at those locations.

Because of the perennial high temperatures, natural wildfires are also a relatively common occurrence that may pose threat to the population. As such, the Civil Defense Office is also responsible for mapping and monitoring vulnerable areas susceptible to fires, such as the identification of dry vegetation.

Another common threat that is often faced by the Civil Defense Office of Niterói are fire balloons. Despite being a punishable offense according to the Brazilian law, building and releasing fire balloons into the air is still a common form of cultural expression in several parts of Brazil. Those balloons, however, pose a serious risk, as their paths are unpredictable — they depend on the direction and speed of the wind in that particular moment — and when they fall, they can start fires. Because of that, detecting, capturing and dealing with the consequences of illegal fire balloons is also a concern of the Civil Defense in Niterói.

Aside from its duties to the population of Niterói, the city's Civil Defense Office also collaborates with its peers from other cities around the country. This happens through the exchange of information among the offices, but also possibly in the form of direct action *in situ* when severe disasters take place in other cities.

3.2 Current Use of Drones

Many of the activities described in Subsection 3.1 can be aided by the usage of drones. Indeed, for the past several years, the office has been using drones for different purposes. The Civil Defense Office holds a *drone operation crew* trained to pilot the equipment for preventive and emergency missions.

One such use is for complementing the analysis of satellite images. When that analysis suggests signs of irregular constructions, for example, the office conducts drone missions over the area in order to obtain more detailed images to confirm or dismiss on the suspicion.

Drones are also used for providing support during natural disasters or wildfires. In this case, the devices can help quickly identifying the extension of the affected area, as well as other potentially useful information, such as available access routes for ground crews.

3.2.1 Actions with Drones during Emergencies

The preventive work conducted by the Civil Defense Office is perhaps the most important because it can avoid threats. Nevertheless, to the general population, the actions of the office are more apparent under emergency situations. Incidentally, these emergencies are currently one of the main use cases of drones by the Civil Defense Office of Niterói. Indeed, despite its drone operation crew existing for just a few years, it already has a significant track record of operations of this kind.

In 2019, for instance, a fire started in a forest area in the neighborhood of Charitas, in Niterói[2]. While handling the fire is primarily a task of the fire department, the Civil Defense Office provided support for the operation. In particular, the drone operation crew conducted survey flights that allowed the response units to visually assess the extension of the fire, as well as to identify the most critical fire spots. The images of that survey also allowed the fire department to anticipate the most likely direction for the spread of the fire and to identify possible routes for the firemen to access the region.

More recently, in 2022, a team of the Civil Defense Office of Niterói was sent to the state of Bahia to provide support to response units of that state during a season of severe rain storms that took place by the end of 2021[3]. One of the main tasks of this team during this event was to help assess the state of hills and other areas under the risk of mudslides. Among other tools, the team employed drones to obtain detailed aerial footage and images that were later analyzed by geologists and engineers to pinpoint risk areas.

A month later, the nearby city of Petrópolis was hit by a heavy storm that cause severe damage to the infrastructure[4] and killed over 150 persons. As they did in the storms in Bahia, a team of Niterói's Civil Defense Office collaborated with the local authorities by using drones to identify areas in risk of mudslides and constructions in risk of collapse. The storm also caused a flooding that dragged vehicles, including two busses that were carried towards a river and sunk. Eventually, the drone operation crew of the Civil Defense Office of Niterói was called upon to help in the searches of missing people. By using

[2] More details (in Portuguese): http://www.sma.niteroi.rj.gov.br/index.php?option=com_content&view=article&id=5966:2019-08-05-19-01-40

[3] More details: https://edition.cnn.com/2021/12/26/americas/brazil-bahia-flooding-w/index.html

[4] More details: https://www.bbc.com/news/world-latin-america-60401611

drones, the search process became much faster, and larger areas were covered more quickly.

Similarly, in June 2022, heavy rains caused destruction in several cities in the state of Pernambuco, in the Northeast of Brazil. Once again, Niterói's Civil Defense Office lent its expertise and performed drone flights with the objective of assessing mudslide risk areas. It also collaborated by inspecting the state of constructions to determine which were safe for the return of the affected families.

3.2.2 Products

The Niterói's Civil Defense Office generates products related to their main actions in the city and services even in other cities. These products are response to other municipal departments about the services provided — *e.g.* Fire Department — and, ultimately, to the population.

Frequently, the crews of Civil Defense use drones to collect data *in situ*. From these data, several information relevant to the incident or occurrence is gathered and reported in documents (products). These products are forwarded to the competent departments of the City Hall so that actions can be taken to avoid or handle the situation. These products are basically reports that can include landslide areas, risk areas, soil typology, affected properties and buildings and so on.

3.3 Demands of Drone Usage

Aside from the current uses described in Section 3.2, other activities of the Civil Defense Office of Niterói could be improved, facilitated or even enabled by the employment of drones with suitable characteristics.

The inspection of constructions is one such activity. Currently, those inspections are done solely *in situ* and, therefore, require a technician to physically attend each building. Periodical drone surveys with sufficiently detailed images could save resources by allowing a preliminary remote evaluation of the state of the constructions. This, in turn, may allow more frequently inspections for each building, reducing the risk of accidents.

Drones could also be used during events with large concentration of people — such as concerts or protests. A drone equipped with loud speakers could be used to disseminate audio messages containing safety instructions or warnings regarding emergency situations. As a more concrete example, the city has siren systems in several mudslide risk areas that are activated when storms are forecast. Drones could improve that by spreading the warnings in regions where the alarm system has not yet been implemented.

Another interesting possibility is the usage of drones for transporting essential supplies — *e.g.*, medication — during rescue operations. They could reach difficult areas quickly and provide some kind of first response before ground crews arrive.

Even in the activities for which the office already uses drones, its role could be expanded for better results. For example, while the office currently uses drones to help identify risk areas and irregular constructions therein, the device's role is secondary, as it is used only as a means for confirming or detailing satellite image analysis. However, satellite images take time to obtain and sometimes are unusable due to the presence of clouds. Thus, instead of a simple tool for confirmation or detailing, drones could be used more frequently as a primary source of the images used for this task, mitigating the aforementioned issues.

Another example is the handling of fire balloons, especially during the times of the year in which this practice is more common. The idea is to follow the path of the balloon in order to guarantee that it will fly to a safe area or to anticipate the areas on which it may fall so that a proper response can be prepared.The office could further mitigate the risks by trying to actively handle them. One possibility would be to use drones to drag or direct the balloon to areas of lower risk. Alternatively, drones could be used to take the balloon down in a controlled manner — for example, by using water or chemicals to cool down the balloon's heat source.

Further notice that drone flights can be simulated in anticipation to a certain mission. By exploiting that, the Civil Defense Office might conduct simulated exercises and use flight simulators to assess the most beneficial manner to deploy drones in different situations, complementing their other teams/actions. This would allow them to maximize the effectiveness of the drones in real emergency situations.

4 CHALLENGES AND INSIGHTS

The activities performed by the Civil Defense Office of Niterói — surveyed in Section 3 — reveal a number of specificities that are, in many regards, different from the most common drone uses. As such, there are many issues identified and unique challenges that need to be addressed, as well as lessons to be learned from the secretariat's experience, providing a vast field of research and for proposals of information and knowledge management and development of appropriate information systems.

4.1 Identified Issues and Challenges

According to the drone staff of the Civil Defense Office, the drones employed in their missions have a flight autonomy of approximately 15 to 20 minutes — depending on the wind velocity and temperature —, impairing actions that demand either long flight times or large areas to be covered. To mitigate this issue, the drone operation crew takes several backup batteries to the missions. Still, this relatively low autonomy results in interruptions in the missions as the drones must return to the ground station so that the batteries can be manually replaced. Also, recharging the depleted batteries on the field is not always easy or fast due to power outlets not always being available on the site. Thus, this can be a limiting factor for the length of the missions.

The weather is another issue. As described in Section 3, several use cases of the Civil Defense Office are concerned with rain-related emergencies. However, rain — especially associated with wind — is a harsh condition for flying. Indeed, several drone models cannot fly under rain. In that case, the team needs to postpone missions and wait for better weather conditions.

Flights are also limited by the range of communication and obstacles between the radio controller and drone. The communication range, in turn, is affected by a number of factors, including interference levels. As of today, the Civil Defense Office uses off-the-shelf drones that are restricted to communication in unlicensed bands — usually, the 900 MHz, 2.4 MHz, and 5 GHz ISM bands. Because of their unlicensed natures and the popularity of technologies such as IEEE 802.11 and Bluetooth, those bands are currently crowded in most urban areas. Thus, the communication between the drones and the ground station can be severely affected, especially in densely populated regions. Indeed, during our interviews, members of the drone operation crew reported more than once situations where the control of the drone became unstable likely due to communication issues.

Another problem reported by the crew is the coexistence between drones and birds. Several missions had to be interrupted because certain species of birds — perhaps feeling threatened by the device — attempted to attack the drone and disrupted the flight. According to the pilots, this is a particularly common occurrence when drones are far away from the ground station. The lack of visual contact with the device makes it harder for the pilots to anticipate the approach of the birds — as they rely solely on the relatively narrow field of view of the drone's camera. Nevertheless, this type of event may cause the drone to crash.

Another challenge is how to conciliate the needs of the Civil Defense Office with the Brazilian drone legislation. For instance, one of Rio de Janeiro's main airports, Santos Dumont, is relatively close to certain regions of Niterói. Because of the risks associated with flying drones nearby airports, whenever a mission requires a drone flight in one of those regions, the Brazilian legislation requires the Civil Defense Office to register the mission with the competent department and wait for the proper permission — in fact, off-the-shelf drones are programmed to recognize the vicinity of airports and avoid entering those areas. While requesting this type of permission can be feasible for routine missions that are planned ahead of time, it can impede the usage of drones for certain emergency actions.

Legislation can also be an obstacle for other types of desirable drone applications. Take, for instance, the idea of using drones to carry fire balloons towards safer areas. Overcoming the drag of a typical balloon requires a drone of considerable size. Aside from all the technical and financial challenges involved in designing and acquiring such an equipment, there are regulatory issues as well — *e.g.*, would there be additional constraints regarding the areas or routes that such a drone would be allowed to fly? what additional permits would be required from the pilots?

Regarding Civil Defense procedures and protocols to generate their products using drones, the agents reported a long time (*e.g.*, weeks) to produce them. They need to collect the data, then process it in office and write the report outlining their conclusions. The faster reports are generated, the faster actions are taken on the incident. This can mean a significant improvement to the final result of the entire operation demanded to the City Hall, and may even save lives.

Regardless of the model of the drone, properly training the pilots is another important aspect. Remember that the Civil Defense Office missions can occur under very challenging circumstances — *e.g.*, under rain, considerable wind. Moreover, the typical missions conducted by the office often involve pushing the drones to their limits in terms of both autonomy and range. Thus, pilots must be well aware of such limits and must be prepared to fly the drone under non-ideal situations.

Finally, we note that a fundamental challenge is choosing the right drone model. Drones can vary widely in a number of ways — *e.g.*, size, flight autonomy, load capacity, accessories. Depending on the type of mission, certain aspects are more important than others. For instance, search missions during a disaster can last for days, thus requiring drones with

Table 2: Summary of the main recommendations for each challenge or demands identified.

Challenges/Demands	Recommendation Summary
Battery autonomy	Multi-UAV, define points in ground for battery swap, hot-swap.
Weather conditions	Investing in waterproof or splash-proof drones.
Network communication	Study and use of LPWAN, 5G, FANET.
Choosing drones	Survey of readily available drones on the market and sensors.
Regulation and Legislation	Reduce bureaucratic processes, flexibilize rules for emergency.
Training agents	Use simulators of drone flight.
Mapping risk areas	Use of infrared/multispectral camera, humidity sensors, embedded in the drone.
Handling fire balloon	Study techniques and procedures to extinguish or redirect balloons.
Building surveillance	Define protocols for the drone structural inspection, knowledge management.
Warning sound messages	Define message and protocol in missions according to historical situations.
Supply delivery	Specify drone capable to transport supply. Define protocols.
More agile processes	Automate procedures to provide (*quasi*) real-time responses while *in situ*.

as much autonomy as possible. However, if the search is carried out in a region of dense vegetation, accessories, such as thermal cameras, might be of great help. Unfortunately, that adds weight, which not only demands a larger, high-capacity drone, but also reduces the autonomy. Indeed, given the wide range of different missions carried out by the Civil Defense Office, it seems unlikely that a single drone model will be able to cater to all requirements.

4.2 Improving or Recommending Drone Usage

In the context of the PDPA, the Civil Defense Office is proposing a series of potential solutions for the demands and challenges mentioned in Section 4.1. Table 2 summarizes the main recommendations, in relation to challenges and demands, as described as follow.

One of the recommendations is related to the battery autonomy issue. A multi-UAV system, also called a *drone swarm*, is a strategy that help solving the problem of covering larger areas (Chen et al., 2020). Instead of using only one drone for a mission, a group of drones is autonomously coordinated in order to embrace more tasks and consequently explore more areas. Another approach to be explored is the organization of strategic battery charging points in the city or at the mission site, *e.g.* placing vehicles in strategic positions for this purpose. Battery hot-swap — changing the drone's battery without restarting their electronic components and, consequently, the previously defined mission — can also reduce the down-time.

For the problem of flying under bad weather conditions, one can consider investing in waterproof or splash-proof drones. This, however, is not trivial, as such models are not commonly designed by manufacturers in order to lower costs and reduce the technical complexity. An alternative for the Civil Defense Office would be to develop a custom drone with this capability, which involves engineering skills.

In terms of enhancing communication, for urban flights that suffer from interference issues in crowded areas, the *Low Power Wide Area Networks* (LPWAN) (Chaudhari et al., 2020) technologies should be considered for ground communication with the UAV. Those technologies — as IEEE 802.11ah and LoraWAN — operate on long distances, low bit-rate and low battery consumption, by exploiting the less used sub-1GHz bands. However, they are specially geared towards low-volume traffic — LoraWAN, in particular —, being perhaps suitable for telemetry and command transmission. Furthermore, the emergent 5G networks can also help meet the communication demands, but the antenna placement of such networks is often optimized for covering the ground — where most of the users of the mobile operators are. That can be a challenge for their application for enabling drone communications (Lin et al., 2019). One can also consider the concept of *Flying Ad Hoc Networks* (FANET), *i.e.*, the usage of a multi-UAV system to extend the communication range by means of multi-hop aerial communication between drones (Chen et al., 2020).

On choosing the drone for a specific demand, a survey of readily available drones on the market — whose purchase is more feasible — is a fundamental step. These drones are typically composed by a body (*e.g.*, rotors, propellers and assembly frame), a micro-controller, a conventional camera and a sensing system (*e.g.*, accelerometers, altimeter, GPS and obstacle sensors). Kits of parts to assemble custom drones are also available. In this case, a study of sensors and actuators is relevant to identify which sensors are more useful for the purposes of civil defense.

Regarding regulation and legislation issues, based on the report of the Civil Defense Office, we notice that is important streamline the bureaucratic processes between the office and the competent government departments — especially, for the emergency missions. Since the Civil Defense Office's services are government-owned, the rules for emergency flights in civilian prohibit areas, such as airports and military zones, could perhaps be flexibilized. Of course, flights themselves cannot become a risk for the population. Thus, this flexibilization might require additional effort from the part of the office, such as stricter licenses for their pilots. A specialized system for a quicker exchange of information between the office and the competent departments could also help, as well as more direct processes.

Properly training agents of the Civil Defense Office is also important. Drones can be used in several situations and, according to the mission, they should be included in the exercise drills. Several situations associated with flight conditions, such as battery life, path choice, communication failures, could be modeled by simulators and help in a mission planning. Exposing the pilot to these situations before they actually occur can be decisive for the success of the actual missions. The usage of simulators for such purposes, however, requires good simulation models for all aspects involved in the mission, including the physics of the flight, but also communication issues, for example.

In the context of mapping and surveillance of disaster risk areas, considering the demands identified in Subsection 3.3, we note that drones are able to measure the condition of soil and vegetation through images, if equipped with infrared and other multispectral cameras. In a first moment, satellite images can detect potential risk areas in a large but distant region. Then, a drone assembled with an infrared camera can examine a specific area in more detail. Drones can also measure the relative humidity of certain regions and other environmental aspects, if equipped with the proper sensor (such as an air humidity sensor). These actions can prevent disasters such as landslides, wildfires and irregular occupation of risk areas.

For handling fire balloons, we see a need for studying techniques that can be used to extinguish or redirect balloons to areas without risk of fire (such as the sea or lake). This is not a trivial issue, as those balloons are generally of large proportions — and, therefore, have too much drag to be pulled or carried by a typical off-the-shelf drone. Even taking down the balloon in a controllable fashion is a challenge, as cooling down their heat source might require large volumes of water or chemicals. As such, we anticipate the need for a multidisciplinary effort for designing and eventually equipping a proper drone with suitable actuators for this task.

In terms of procedures and protocols while the civil defense operations with drones, some procedures can be automate to provide (quasi) real-time responses. We identified many information that can be processed *in situ* rather than of being processed later in the office. Thus, conclusions can be drawn more quickly, making it possible to expand data collection to capture additional information. Taking the example of the inspection of risk areas, agents can compute information on risk points, based on images, still in the field.

Defining action protocols according to a specific mission is also key to enable the use of drones for several demands such as building surveillance, warning sound messages and supply delivery. Protocols must define important stages of knowledge management and decision-making, such as the processes of measuring data, generating storing and disseminating the information and knowledge, and making decisions based on acquired knowledge. Effective information and knowledge management techniques, especially designed for the problems discussed, are therefore crucial for optimizing processes in the secretariat.

Table 3 summarizes the current use of drones in the Civil Defense Office by roles (see Table 1) and also the recommendations for future drone usage. The difference between the current and future use of drones by the office is highlighted in the fourth column, labeled as "Future Drone's Use".

5 CONCLUSION

Drones are devices responsible for collecting information from sensors carried by them. The relative low cost and easy access to drones — especially, for off-the-shelf models — has opened-up a large number potentially useful applications. But they use often complex procedures and are therefore candidates to benefit from information and knowledge management systems. Smart cities, in particular, seem to be a niche that can greatly profit from the flexibility of drones. In this context, Niterói's Civil Defense Office is a pioneer in the usage of drones for a plethora of rescue and risk prevention activities in Brazil.

In this paper, we reported on the experience of the office in using those devices. We surveyed their current use cases, detailing how drones have been or could be helping the office succeed at its missions. We also reported issues found by the office's pilots and technicians during their years using drones, as

Table 3: Summary of current use of drones in the Civil Defense Office by roles and recommendations for future drones' use.

Role Id.	Current Drones' Use	Summary of the Current Usage	Future Drones' Use	Recommendation
1	yes	Drones only inspect risk areas using conventional cameras.	yes	Drones can map and identify risk areas using infrared cameras.
2	yes	Drones only inspect risk areas using conventional cameras.	yes	Drones can inspect a risk area using infrared cameras.
3	no	-	yes	Define protocols to include drones in building inspection.
4	no	-	yes	Drones can be used to send sound alert messages to the civilians.
5	no	-	yes	Apply drones in exercise drills; use simulators of drone flights.
6	no	-	yes	Drones can be used to transport supplies for a risk area, if needed.
7	yes	Drones capture conventional images of areas hit by disasters.	yes	Drones can automate the current process and improve evaluation.
8 9		Not applicable.		
10	no	-	yes	Drones as a tool to assist in the training of human resources.
11	no	-	yes	Data and procedures using drones can feed the national system.

well as other usages that the office envisions for those devices. We also looked at the existing challenges in meeting those future uses, and discussed possible paths for realizing the drones' full potential for the Civil Defense Office.

Towards that goal, our analysis has revealed obstacles in both technical and legislative aspects of drone usage. For example, autonomy and flight range seem to often hinder envisioned drone applications. As battery technology evolves, those issues should be mitigated to a certain extent. Ditto the issues with communication range, that might become less pronounced with the proliferation of 5G. Even so, regulatory obstacles also need to be overcome both by the modernization of the relevant legislation, but mainly by the cooperation between the regulatory bodies and the Civil Defense Office to find safe yet streamlined processes for the authorization of time-critical missions and the usage of specialized drones.

ACKNOWLEDGEMENTS

This work is funded by the PDPA program of the City Hall of Niterói.

REFERENCES

Alsamhi, S. H., Ma, O., Ansari, M. S., and Almalki, F. A. (2019). Survey on collaborative smart drones and internet of things for improving smartness of smart cities. *IEEE Access*, 7:128125–128152.

Ayamga, M., Akaba, S., and Nyaaba, A. A. (2021). Multifaceted applicability of drones: A review. *Technological Forecasting and Social Change*, 167:120677.

Chaudhari, B. S., Zennaro, M., and Borkar, S. (2020). LPWAN technologies: Emerging application characteristics, requirements, and design considerations. *Future Internet*, 12(3).

Chen, W., Liu, J., Guo, H., and Kato, N. (2020). Toward robust and intelligent drone swarm: Challenges and future directions. *IEEE Network*, 34(4):278–283.

de Moor, J. M., Stix, J., Avard, G., Muller, C., Corrales, E., Diaz, J. A., Alan, A., Brenes, J., Pacheco, J., Aiuppa, A., and Fischer, T. P. (2019). Insights on hydrothermal-magmatic interactions and eruptive processes at Poás volcano (Costa Rica) from high-frequency gas monitoring and drone measurements. *Geophysical Research Letters*, 46(3):1293–1302.

Giordan, D., Hayakawa, Y., Nex, F., Remondino, F., and Tarolli, P. (2018). Review article: the use of remotely piloted aircraft systems (RPASs) for natural hazards monitoring and management. *Natural Hazards and Earth System Sciences*, 18(4):1079–1096.

Gohari, A., Ahmad, A. B., Rahim, R. B. A., Supa'at, A. S. M., Abd Razak, S., and Gismalla, M. S. M. (2022).

Involvement of surveillance drones in smart cities: A systematic review. *IEEE Access*, 10:56611–56628.

Hassanalian, M. and Abdelkefi, A. (2017). Classifications, applications, and design challenges of drones: A review. *Progress in Aerospace Sciences*, 91:99–131.

Jayaweera, H. M. and Hanoun, S. (2020). A dynamic artificial potential field (D-APF) UAV path planning technique for following ground moving targets. *IEEE Access*, 8:192760–192776.

Jensen, O. B. (2016). Drone city – power, design and aerial mobility in the age of “smart cities”. *Geographica Helvetica*, 71(2):67–75.

Katila, C. J., Di Gianni, A., Buratti, C., and Verdone, R. (2017). Routing protocols for video surveillance drones in IEEE 802.11s wireless mesh networks. In *2017 European Conference on Networks and Communications (EuCNC)*, pages 1–5.

Kim, H., Mokdad, L., and Ben-Othman, J. (2018). Designing UAV surveillance frameworks for smart city and extensive ocean with differential perspectives. *IEEE Communications Magazine*, 56(4):98–104.

Lin, X., Wiren, R., Euler, S., Sadam, A., Määttänen, H.-L., Muruganathan, S., Gao, S., Wang, Y.-P. E., Kauppi, J., Zou, Z., and Yajnanarayana, V. (2019). Mobile network-connected drones: Field trials, simulations, and design insights. *IEEE Vehicular Technology Magazine*, 14(3):115–125.

Reis, L. C. D., Bernardini, F. C., Ferreira, S. B. L., and Cappelli, C. (2021). An ICT governance analysis for the digital and smart transformation of brazilian municipalities. In *DG.O2021: The 22nd Annual International Conference on Digital Government Research*, DG.O’21, page 327–338, New York, NY, USA. Association for Computing Machinery.

Shavarani, S. M., Nejad, M. G., Rismanchian, F., and Izbirak, G. (2018). Application of hierarchical facility location problem for optimization of a drone delivery system: a case study of amazon prime air in the city of san francisco. *The International Journal of Advanced Manufacturing Technology*, 95(9):3141–3153.

Swinney, C. J. and Woods, J. C. (2021). The effect of real-world interference on cnn feature extraction and machine learning classification of unmanned aerial systems. *Aerospace*, 8(7):179.