COLLaborative network on unmanned **A**e**RI**al **S**ystems

D4.3b – Overview of currently used auxiliary systems and available capabilities, including common practices: assessment and recommendations for future use in civil protection and disaster management

WP4 – Solutions for data analysis and data sharing and auxiliary support systems

Deliverable type: Report

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COLLARIS partner organizations:

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Executive Summary

Deliverable 4.3 focuses on identifying the most commonly used auxiliary support systems for unmanned aerial systems (UAS) in disaster management and their available capabilities. The first version of this report was handed in in July 2023 (M7) and consists of the results from desk research and a quick poll. The report was then updated successively during the project and is finalized in this updated version (D4.3b).

An auxiliary support system for UAS can be anything that is added to the UAS and that helps in its operability. This report focusses mainly on different sensors as well as delivery platforms that are of use in disaster management: visual RGB-cameras, thermal imaging (or infrared) cameras, multispectral cameras, laser scanners / LiDAR, radars, chemical sensors, search lights, microphones, loudspeakers, delivery platforms, and RTK base stations.

RGB-cameras are usually sold as a part of commercial UAS and are used as "the eye in the sky" in the different phases of disaster management. The photos or videos the cameras produce aid situation awareness pictures as well as post disaster damage assessment by getting an overview of the situation from above. They can also aid in search and rescue (SAR) missions, helping to identify survivors or assess hazardous conditions. However, in many cases cameras are supported by other sensors – like thermal imaging cameras.

Thermal imaging cameras are used for firefighting purposes to detect the source of structural fires and embers for which an RGB-camera is insufficient. At night, they can also aid SAR operations to search for victims in the dark. **Multispectral cameras** are particularly deployed to detect changes in vegetation health and land cover, e.g., during or after a wildfire to assess the burnt area or to help with firefighting strategies by identifying natural firebreaks. **LiDAR technology** aids disaster management in different fields, for instance, in the response phase after an earthquake for post-event imagery to assess the damage or to identify and map landslides. It also receives attention in wildfire management practices, e.g., for mapping canopy fuel attributes that are needed for wildfire predictions. **Radar systems** can be of great help in SAR operations where debris and other forms of substances cover an area where people are buried. A UAS with a radar system enables the safety of personnel in hazardous environments because rescue personnel can be positioned in a secure location while the drone is monitoring the terrain. **Chemical sensors** can detect different gases and chemical components, e.g., in forest fires to monitor air quality and smoke components, or detect toxic gases or chemical leaks. UAS equipped with chemical sensors ensure the safety of emergency personnel on the ground as the extent of chemical contamination can be assessed without people having to enter the area in question.

Search lights enable the usage of UAS at night and in low-light conditions, so they can continue to be the "eye in the sky", especially when other low-light-operating sensors (e.g., thermal or multispectral cameras) are not available. Thus, they are particularly interesting for organisations that predominantly use UAS and RBG cameras in SAR operations. **Microphones** on UAS for a more effective and efficient disaster management are still developed and researched and, thus, not yet used in practice. However, they are promising auxiliary support systems that could be used in the future if successfully trained by artificial intelligence to detect sound patterns such as shouting and clapping. **Loudspeakers** on UAS are mainly used to disseminate information, particularly in remote areas, or in areas with disrupted infrastructure. **Delivery platforms** for drones play a crucial role in disaster management by facilitating the transportation of vital supplies, equipment, and resources. They can enhance response capabilities, bridge logistical gaps, and provide immediate relief to affected populations in times of crisis. Last but not least, **RTK base stations** improve the accuracy of GPS of UAS. This auxiliary support system is of particular interest in cases when precise positioning is crucial for disaster management practices.

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About COLLARIS

Scientific advances as well as fast-evolving drone technology and its applications have today become indispensable in all phases of the disaster risk management cycle. COLLARIS is a capacity-building initiative to develop a sustainable European network of scientific, engineering, and end-user expertise related to unmanned aerial systems (UAS) in civil protection and disaster response. COLLARIS covers the following thematic focus areas:

- Identification and sharing of operational procedures, lessons learnt, and best practices using UAS
- Elaboration of air traffic management challenges, solutions, and operational practices
- Acquisition of solutions for data analysis and data sharing, as well as auxiliary support systems (e.g., simulators)
- Development of methods for increasing end-user competences
- Foresight of new developments and future use case scenarios to identify tomorrow's needs and gaps, technological capabilities, and their potential applications

The general concept of COLLARIS is based on two assumptions: That the technical capabilities related to UAS will continue to develop rapidly, as will the scope of their application for civil protection and crisis management purposes; and that the gap between these recently created technical capabilities and the practical needs and operational practices of civil protection not utilising them yet will remain a permanent challenge. Therefore, there is a clear need for establishing a stable long-term mechanism to continuously support the civil protection community in gradual implementing innovations enabled by UAS developments. The COLLARIS-based community will make an important contribution to achieve that.

COLLARIS will offer a networking platform as part of the Union Civil Protection Knowledge Network for information exchange and experimentation with advanced concepts of UAS for disaster response and crisis management. These activities are accompanied by thematic workshops, webinars, and moderated discussions as well as trials and embedded first responder trainings, aimed at increasing the efficiency of UAS operations by bringing knowledge closer to operational use.

Representatives of civil protection authorities at all levels, first responders, crisis management practitioners, and researchers interested in issues related to further development and operational use of UAS in their activities are cordially invited to join the COLLARIS Network initiatives.

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List of Abbreviations

CTR	Controlled Traffic Region
DSM	Digital surface model
DTM	Digital terrain model
GPR	Ground penetrating radar
LiDAR	Light detection and ranging
RGB	Red-green-blue
RTK	Real Time Kinematics
SAR	Search and Rescue
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle

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1. Scope and approach of this report

This report is part of the COLLARIS Network project and constitutes the final version of Deliverable 4.3. The biggest changes in comparison to the first version were made to the structure which now follows the disaster management cycle, sorting the described practices with auxiliary support systems into them. The report aims to identify the most commonly used auxiliary support systems in disaster management and their available capabilities. To achieve that, a desk top research was conducted. This report's search strategy identified relevant literature with the search terms 'drone' OR 'UAS' OR 'UAV' AND 'disaster management'. In a second step, literature was selected that included aspects of auxiliary support systems. Hence, the auxiliary support systems most frequently mentioned in literature served as a starting point. A google search and a search on the websites of the most prominent suppliers complemented the information about the currently available capabilities on the market.

To examine if the selected auxiliary support systems in the literature are currently used in practice by COLLARIS stakeholders as well, a quick poll (n=9) was sent out in late June 2023 and concluded in the first week of July 2023. The results of the poll provided further input to the content of the report and additional auxiliary support systems mentioned in the survey were included. The report then was further enriched by qualitative interviews and participant observation of the trials conducted in COLLARIS, as well as information gathered during the preparation of the small-scale foresight report (D3.3).

2. Auxiliary support systems for UAS in disaster management

Generally, the term 'auxiliary support system' refers to a set of tools, equipment, or processes designed to provide assistance or backup to a primary system. These systems are commonly used in various domains, including technology, engineering, healthcare, and logistics, in order to enhance the performance, reliability, or functionality of the main system. In the case of UAS in disaster management, the UAS can be seen as the primary system while everything that is added to the UAS can be subsumed under the term 'auxiliary support system'. With that definition, it is debatable if a camera which is oftentimes the main reason to acquire a UAS can be seen as an auxiliary support system or if the camera is part of the primary system because without it there would be no primary system. Nonetheless, we included cameras in the overview for the sake of completeness. Because of the devices and sensors that can supplement UAS, it is possible to identify or assess different risks.
Within COLLARIS, we are focussing on payload systems such as the aforementioned cameras, sensors, or specialized equipment for the use in all phases of disaster management.

In this report, the practical implications of auxiliary support systems for disaster management are set out for the different phases of disaster management. We use the term 'practices' to describe the activities and the 'doing' during the different phases of disaster management (response, recovery, prevention and preparedness).

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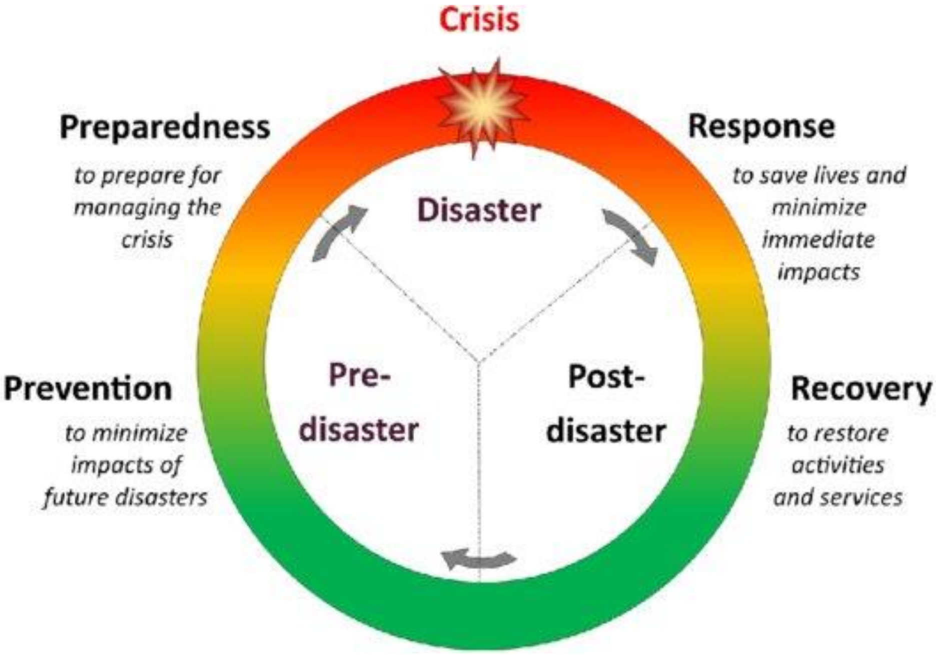

Figure 1: Disaster management cycle (Le Cozannet et al., 2020)

3. Available systems and their capabilities

3.1. Visual RGB-Cameras

Visual red-green-blue (RGB) cameras are probably the most widely used auxiliary support system for UAS in disaster management. In this section, we are referring to cameras as devices that form an image using visible light (Karma et al., 2015). A systematic literature study analysed 635 relevant articles published between 2006 and 2021 from which statistics in terms of geography, drone hardware, disaster management application, drone remote sensing data type and analysis method were derived (Kucharczyk & Hugenholtz, 2021). A vast majority of UAS employed in the analysed studies used RGB cameras (87%). The authors attributed that high usage of RGB cameras to their supply with consumer-level-drones and their usage in structure-from-motion, a photogrammetric range imaging technique for estimating three-dimensional structures from two-dimensional image sequences. After appropriate processing of the data derived from RGB cameras – currently still images – the following can be obtained: point clouds, orthophoto maps, numerical surface models (DSM), numerical terrain models (DTM), and 3D models. Such products find primary applications mainly in geodesy and cartography. In addition, they are applied in areas (contextual for this report) such as preventive digital preservation of monuments, calculation of volumes of industrial heaps (stocks) and also rapid 2D mapping of environments altered by, for example, a disaster. Photogrammetry executed by UAS is referred to as low-altitude photogrammetry to distinguish it from aerial photogrammetry performed by manned aircrafts, albeit the practical differences are beginning to fade.

To have a better understanding what the capabilities of RGB cameras already installed on UAS are, we look at the range of UAS that DJI offers. DJI was chosen as an example because more than half of the studies (51%) of the literature review of Kucharczyk and Hugenholtz used DJI multirotors. The model Mavic 2 Enterprise Advanced, for instance, which is sold for firefighting purposes (amongst others), has a 32x zoom and a maximum resolution of 8,000×6,000 pixels. The cheapest model currently available online possesses a maximum resolution of 5,472×3,648 pixels which is much less than the professional model but, depending on the reason and area of application, this might suffice. Kucharczyk and Hugenholtz (2021) also attribute the large uptake of consumer-level multirotors to their affordability and simplicity to use. The method of application is a more important factor than the native resolution of the camera itself – the size and characteristics of the sensor will affect the dynamic quality of the image, and for operators analysing the image in flight, the final resolution will depend on the ability to transmit the image to the controller device and the resolution and size of the display. Besides the resolution of the camera, its zoom capabilities are an important factor to consider when purchasing a camera system. Zoom allows for observing objects far away, e.g., objects that are further away than legal flight distance limits or in restricted areas where UAS are not allowed to fly, for instance over crowds. It also helps to take a closer look into places where it might not be physically possible to fly, e.g., between trees or into a ravine.

Another scoping review about UAS and disaster management analysed 52 papers in total published from 2009 until 2020 (Mohd Daud et al., 2022). Two thirds of the studies analysed focused on the use of cameras with different scopes and in different phases of disaster management. For instance, during the response phase, studies used UAS with camera systems to assess the damage or the hazard, and to use the information in their situation or awareness picture. In the preparation for disasters, cameras were also used to assess the risk and vulnerability of an area.

This predominance of camera systems as auxiliary support systems has multiple reasons:

1. Availability: Almost all commercially available UAS are equipped with a camera system and, therefore, used as such.
2. Intentionality: One of the main incentives to acquire a UAS is its ability to be "the eye in the sky" and, hence, to use its camera system for situational assessments from above (see small-scale foresight report, D3.3).
3. Convenience: UAS and its camera system is an easy-to-use and easy-to-learn system which is comparatively cheap. To achieve similar outcomes in terms of reconnaissance and situational awareness pictures, other methods such as using helicopters or satellite imagery are oftentimes more difficult to attain (also in terms of time required to obtain them) and more expensive than UAS.

3.2. Thermal imaging sensors (infrared)

Thermographic sensors are often referred to as infrared cameras or thermal imaging cameras and can be described as "devices that form an image using infrared radiation" (Karma et al., 2015). As the name suggests, thermal imaging cameras can detect heat (e.g., warm bodies) and reproduce this information via different colouring in their video feed. Therefore, they can be of good use for different disaster management practices, most notably in firefighting and for SAR operations. As Burke et al. (2019) describe, "humans (and other warm animals) appear as bright objects in thermal images, whereas, in conventional visible spectrum (RGB) footage, all objects appear with the same brightness. This means that they can more easily be picked out by the naked eye in thermal images than in RGB images in many cases."

Prices of thermal imaging cameras as payloads for drones vary considerably depending on their features. These features include (1) thermal sensitivity, hence, the camera's ability to detect and display small differences in temperature accurately. Higher thermal sensitivity allows for better detection of heat signatures and more precise temperature distinctions. (2) Resolution, normally measured in pixels: The higher the resolution, the more detailed the thermal images are. (3) Image and video capture: Thermal imaging cameras can capture both still images and video footage. Some cameras offer features such as digital zoom, image enhancement, and the ability to record and stream a thermal video. Furthermore, there may be additional features such as multiple colour palettes, image blending (overlaying thermal and visual images), GPS tagging, and integration with mapping or analysis software that add to the price of the sensor.

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A night vision system complemented by a focused infrared beam or dedicated laser can also be used to indicate points of interest during night-time, such as the waypoints on the path to the casualty. However, a system using such functionality relies on rescuers on the ground wearing night vision goggles which is not standard outside military circles at the moment. Night vision cameras allow the observation in low-light conditions, e.g., through the diffusion of light from the moon or stars. They are equipped with a passive image intensifier that amplifies the light intensity from residual to observable values. Some cameras (so-called I2, or Illuminated Infrared) allow, in the event of total absence of light, active observation using infrared illumination.

Although night vision technology is popular in other industries, it is not widely used in disaster management. One of the few examples is the DJI SkyPort-mounted and DJI Pilot-compatible RMUS Nighthawk camera with a 1080p sensor resolution and 10x optical zoom with an additional infrared illuminator with a 300m range. Given the price of the product ($6,000 in July 2023), this solution does not appear to compete with thermal imaging cameras.

3.3. Multispectral cameras

Another auxiliary support system in disaster management that was mentioned in the quick poll were multispectral cameras. They are able to capture imagery across multiple spectral bands, providing detailed information on the extent and nature of damage caused by disasters. The camera uses filters to separate light into different bands or wavelengths, and, therefore, can detect changes in vegetation health, land cover, and water bodies, enabling a comprehensive assessment of the impacted areas (Coffey, 2012). By capturing data across different spectral bands, multispectral cameras can detect stress levels, vegetation recovery, or changes in plant physiology, aiding in post-disaster ecosystem recovery planning and management. For water bodies, it is possible to analyse and monitor environmental factors such as water quality, pollution levels, or sedimentation. Multispectral cameras can also aid in the assessment and monitoring of critical infrastructure, such as bridges, roads, or buildings, affected by disasters. They can detect structural changes, identify potential vulnerabilities, and provide valuable data for evaluating the safety and integrity of infrastructure post-disaster.

3.4. Laser scanner / LiDAR / laser rangefinder

LiDAR – Light Detection and Ranging — is a remote sensing method used to examine the surface of the Earth. It uses light in the form of a pulsed laser to measure ranges (variable distances) to the surface (National Oceanic and Atmospheric Administration, 2023). This results in a point cloud because the laser pulses create data when they are pinging back from objects on the ground. The point cloud is used as the raw material for 3D models. This is the main difference from other 3D modelling systems like photogrammetry where thousands of individual photos are taken and put together to create a model. On the commercial market, the most common way to obtain a LiDAR UAS would be to purchase (or already own) a UAS with a large enough payload to carry the LiDAR system and compatible software. The weight of LiDAR systems varies from around 1kg to up to 7kg.

A laser rangefinder is a device that uses a laser beam to accurately determine the distance between the device and a target object. In more advanced applications, the device triangulates that reading, compares it with its position and a DSM model (processed onboard, edge computing approach), and provides the operator with easily shareable coordinates of that point of interest. Thus, a rangefinder can be used to define the coordinates of locations hard to describe otherwise (e.g., a spot on a flat meadow) that can be instantly shared with rescuers on the ground, without post-processing currently required for LiDAR. Other usage can be marking a digital pathway for navigating dangerous terrain – such as peatland underground fires.

3.5. Radar

A radar system can be summed up as a "device that measures the reflection of electromagnetic waves if they meet an obstacle in the propagation direction" (Karma et al., 2015). Generally, these sensors are used for locating, tracking, and recognizing various objects at large distances. They can detect faraway objects under adverse weather conditions and determine their range, or distance, with precision. Radars are non-contact sensors and also suitable for measuring physiological signs from people on the ground if they are deployed on a UAS (Rong et al., 2021).

One example of a popular radar system is the Zond-12e Drone 500a GPR system. It can be used for both airborne and terrestrial surveys and, therefore, comes in two versions. The radar system's weight depends on which system is chosen. The airborne version with a mounting kit weights 3.3 kg, while the terrestrial system weights 8.2 kg with its protective transportation box and tow rope. Hence, one deciding factor might be the capabilities of the drone itself: the payload carrying capacity and, subsequently, the drone's battery life play an important role here.

3.6. Chemical and electrochemical sensors

Chemical sensors come in a wide variety for many different purposes. Their main attribute is to detect different gases and chemical components – depending on which sensors are applied. McGonigle et al. (2008), for instance, used a UAS equipped with an ultraviolet spectrometer, an infrared spectrometer, and an electrochemical sensor for volcanic gas measurements. These sensors allowed them to estimate the fluxes of SO_2 and CO_2, "which are crucial for revealing the geochemical condition of erupting volcanoes" (Giordan et al., 2018, p. 1088). More generally, chemical sensors can be applied in forest fires to monitor air quality and smoke components (such as permanent gases, volatile organic compounds, semi-volatile organic compounds, and particles) (Karma et al., 2015).

There are different sensors on the market which vary in their features and capabilities. Gas-specific sensors, for instance, are designed to detect and measure specific gases or volatile organic compounds. These sensors are often used in applications such as detecting toxic gases or hazardous substances. They are the cheapest option of chemical sensors while their cost depends on factors like sensitivity and accuracy. Multispectral sensors, on the other hand, can detect and measure multiple types of gases simultaneously. They offer broader capabilities in terms of detecting various chemical compounds and provide more comprehensive data for analysis. On the end of the price spectrum lie hyperspectral sensors. They provide even higher spectral resolution and can detect a wide range of chemical compounds or pollutants with greater precision. These sensors are often used for detailed environmental monitoring and analysis.

3.7. Searchlights

Search or spotlights are an important payload for UAS in SAR operations. They provide powerful and focused illumination during low-light conditions or at night. This capability helps search and rescue teams to locate victims and assess the extent of damage through improved visibility for both the drone operator and the adjacent visible camera systems and on-ground emergency responders.

Different UAS manufacturers offer compatible searchlights for their commercial drones and different price categories are available. Cheaper searchlights might offer only 13.5 lux for illuminating 30 meters and a light weight (210-250 grams), while the more expensive models offer more than 10.000 lumens for up to 200 meters and are approximately twice as heavy (500 grams). Searchlights may differ in the way they are fixed (course / on a rotating gimbal).

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3.8. Microphones

Microphones might not be the first auxiliary support systems that comes to mind when thinking about deploying UAS in a crisis or disaster context. However, in recent years using microphones on drones to detect cries for help and signals from survivors is getting increased attention in research (also known as drone audition) (Deleforge, 2020).

An ongoing project of the Fraunhofer Institute for Communication, Information Processing and Ergonomics is developing a technology to detect cries for help and signals from buried victims in-flight and simultaneously pinpoint the victims' location. For this approach to work, an AI is trained to suppress ambient noise, for instance, rotor noises of the drone, and to detect sound patterns such as shouting and clapping (Varela & Wirth, 2021). Microphones could complement vision in situations where visual feedbacks are limited due to bad lighting conditions (darkness, fog) or obstacles limiting the field of view. Nonetheless, there is no ready-to-buy solution on the market right now and, therefore, microphones used for these situations are only a thing to look out for in the future. While microphones that could be mounted on a UAS do exist, the practical use of it would be limited due to the noise the UAS makes and the need for the pilot or another person to intensely focus on possible sounds. Because of that, microphones were not included in the quick poll.

3.9. Loudspeakers

Loudspeakers as payloads for UAS in disaster management recently attracted some attention from practitioners. Loudspeakers produce acoustic signals which are mostly used for conveying messages to people. During the COVID19-pandemic, for instance, UAS equipped with loudspeakers were used to communicate rules and government mandated precautions to residents (Gupta et al., 2020).

Loudspeakers designed for drones are typically compact and lightweight while still providing sufficient power and amplification to project audio effectively. It is important that the loudspeaker can produce clear and high-quality sound over a certain distance to ensure effective communication. Clear and intelligible sound is crucial for transmitting messages and instructions accurately, especially in noisy or crowded disaster scenarios. Some loudspeakers offer additional features such as a remote control or the ability to program them which allows for adjusting the volume or selecting pre-recorded messages.

3.10. Delivery platforms

The idea behind delivery platforms for drones mainly is to effectively transport supplies and equipment in disaster scenarios. They are designed to carry payloads of various sizes and weights. The payload capacity depends on the specific drone model and delivery platform configuration. It can range from a few hundred grams to several kilograms, allowing for the transportation of diverse supplies and equipment. It is crucial that the payload is securely attached and stabilized in-flight to minimize the risk of payload detachment or loss. Some delivery platforms are equipped with release mechanisms that allow controlled and precise payload deployment. This capability enables drones to drop, rappel or release payloads at designated locations, ensuring accurate delivery and reducing the risk of damage to the cargo, people, or the environment.

Delivery platforms for drones play a crucial role in disaster management by facilitating the transportation of vital supplies, equipment, and resources. They can enhance response capabilities, bridge logistical gaps, and provide immediate relief to affected populations in times of crisis. Many delivery platforms are designed to be customizable and compatible with different drone models. This flexibility allows for the adaptation of the

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delivery platform to fit the specific payload requirements and ensures seamless integration with various drone systems.

It is important to note that the specific capabilities of delivery platforms may vary depending on the manufacturer, model, and purpose of use. When selecting a delivery platform for drones in disaster management, it's crucial to consider the payload requirements, compatibility with the drone system, and the operational needs of the specific disaster response scenario.

3.11. RTK base stations

RTK (Real Time Kinematics) base stations were another auxiliary support system that was mentioned by the participants of the quick poll. As it is not added on to the drone per se but improves its data quality, it will only be briefly mentioned. In cases when the accuracy of positioning is crucial for the practices in disaster management where UAS are employed, adding an RTK base station for the drone may make sense. Most commercial drones use GPS units, gyroscopes, accelerometery and compasses. However, the accuracy of these devices may be flawed due to weather conditions, terrain, distortions of the GPS signals or the quality of the device itself (JOUAV, 2022). The RTK base station has the capability to correct GPS position data in real time accurate to a centimetre. Thus, an RTK base station provides highly accurate geolocation data for drones. By establishing a known reference point with known coordinates, the base station helps improve the positional accuracy of the drone's GPS receiver. This enables precise mapping, surveying, and geospatial data collection in disaster-affected areas which contributes to a more effective response coordination, damage assessment, and informed decision-making. Additionally, the utilisation of RTK system improves its positional accuracy in high-interference environments, e.g., with high electromagnetic radiation.

The main benefit of RTK base stations is the accuracy in determining the position of the UAS for data collection and monitoring. This enables the UAS to fly in confined spaces and close to objects which in turn facilitates the capturing of clearer, more precise photos. Additionally, the RTK also permits precise geotagging of photos and videos for future analysis (JOUAV, 2022).

Nonetheless, the quality of position data may be misconstrued if a constant and stable link to the base station is interrupted. This interruption can be caused by trees, mountains, or because the distance to the base station is too far, and, thus, lead to a disrupted signal which can lead to a loss of calibration data (JOUAV, 2022).

An alternative to RTK is Post-Processing Kinematics (PPK) technology. As the name suggests, PPK does not perform GPS positioning during the flight of the UAS, but afterwards. It is quite similar to RTK technology but with its calculation taking place post-flight, high position accuracy is more easily obtained because PPK does not rely on an undisrupted data chain.

Generally, other forms of GPS positioning can be used for marking a point and export and share its coordinates to a GIS system. This is a valuable tool for marking casualties, missing persons or the safe passage for vehicles.

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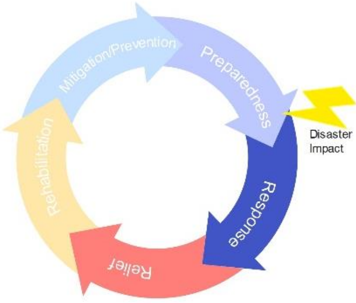
4. Practices in disaster management

4.1. Response and relief

During the disaster response and relief efforts, UAS can be of immense help to expand the situational picture. Because of the extent that UAS can be used in this phase, we included subchapters here for the different auxiliary support systems. As for the other phases of disaster management, the common practices and use of UAS are fewer, thus, we refrained from subdividing into the different auxiliary support systems for better readability.



4.1.1. Cameras: RGB, thermal imaging, and multispectral cameras

The most commonly used auxiliary support system, according to the poll, were RGB-cameras. Thermal imaging cameras were the second most frequently mentioned auxiliary support system in the quick poll. 67% of the participants already use them in their organisations. For that reason, we grouped them together here in this subchapter. During an event, UAS equipped with cameras are used for reconnaissance flights to help with situational awareness for disaster response. Aerial imagery and videos captured by drone cameras help responders understand the scale, scope, and evolving conditions of the area. This information assists in planning response strategies, resource allocation, and identifying potential risks or hazards. As an example, camera imagery can help to obtain geographical information like the direction of the fire or firebreaks in the area as well as in decision-making and safeguarding personnel.

Cameras on UAS also play a crucial role in locating and identifying individuals in need of rescue or assistance. Live video feeds or recorded footage from drone cameras can aid in search efforts by providing real-time or post-mission analysis of disaster areas, helping to identify survivors or assess hazardous conditions.

For firefighting purposes, thermal imaging cameras are used for different objectives. A synchronized daylight video feed coupled with an infrared thermal feed, for instance, can be used to locate the source of structural fires (Rajan et al., 2021) or wildfires as the thermal cameras allow it to see through thick smoke and enable the detection of hot-spots during the mop-up phase of a wildfire. An additional benefit of thermal imaging cameras lies also in the detection of embers of wildfires which are practically impossible to spot via an RGB camera (Rajan et al., 2021). Also, multispectral cameras are occasionally used during wildfires for searching for natural firebreaks such as deciduous treelines which aids decision-making and firefighting strategies.

Although thermal imaging is most commonly associated with the observation of heat-emitting elements (fires, overheating of consumables of the linear infrastructure of electricity grids, inspection of the condition of solar panels), another example of an application field could be floods. Efforts are currently underway to assess the potential for the use of infrared sensors in the detection of embankment wear during floods (early symptoms of embankment failure – hydraulic punctures, piping, soaking, fresh underflows and cold water pools near the embankment) (Borges et al., 2023). Therefore, UAS equipped with infrared cameras could be deployed in the early response phase of a disaster to serve as a sensor for early warning. This may seem like an action associated with disaster prevention rather than disaster response, but it is in fact a response activity since the reaction time is measured in hours.

For water rescue, thermal imaging significantly facilitates the detection of kilwater (a mark on the water caused by an object moving on/near its surface). The flood context of using thermal imaging has broad potential. Experts participating in the 2023 Trial of COLLARIS in Poland surmise that under the right conditions, embankment seepage can be detected early in this way, but precise measurements of water temperatures (outside the embankment) during a real emergency have to be made to confirm this hypothesis.

Figure 2: Aerial view of a fire in an empty field from a UAS with an RGB-camera (https://www.flickr.com/photos/botanic-gardens-sydney/51260877133/in/photostream/)

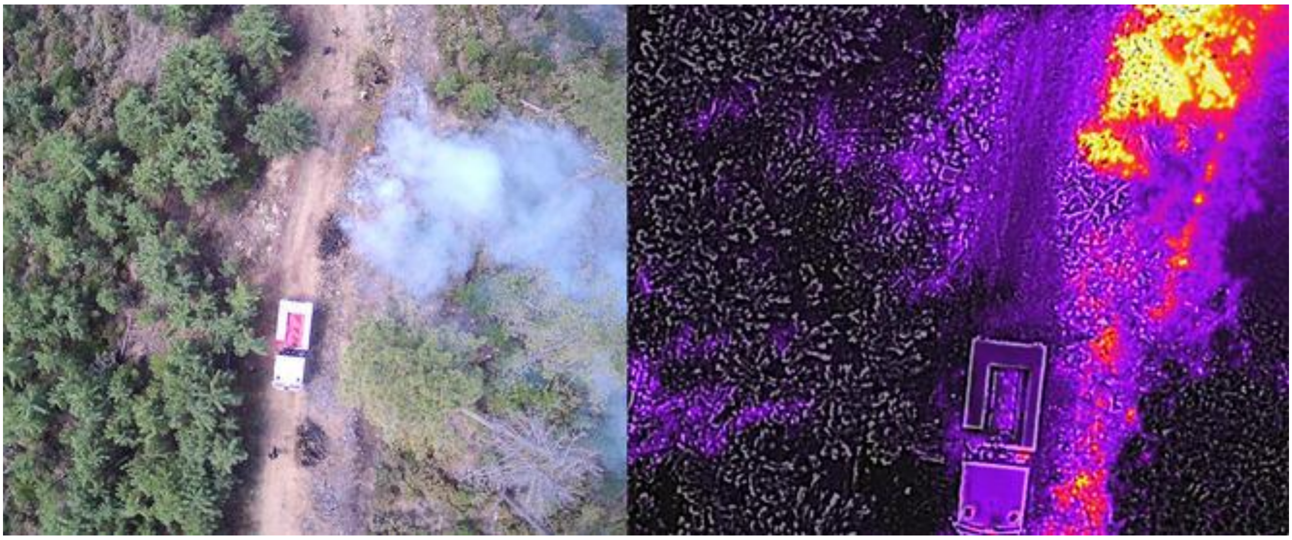


Figure 3: Infrared (right) and visible-spectrum images (left) taken by a drone of a controlled burn. Pictures by Lucile Rossi.

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4.1.2. Aerial Laser Scanning / LiDAR

LiDAR technology is used in different fields of crisis management. In a seismic context for instance, research and the use of UAS with LiDAR is relatively recent according to Antoine et al. (2020). It is mainly used in the response phase to earthquakes for post-event imagery to assess the damage.
In case of an already existing wildfire, LiDAR can serve as a tool for the analysis of smoke clouds resulting from large forest fires (Moran et al., 2020). Utkin et al. explain how it works: “When the laser radiation illuminates a target, such as a smoke plume originating from a forest fire, part of the incident radiation is backscattered, the intensity of this radiation is measured as a function of time by a suitable detector, and the resulting signal is analysed by artificial intelligence methods” (Utkin et al., 2011, p. 41). This helps identifying if the smoke originates from a wildfire or if it has another cause.

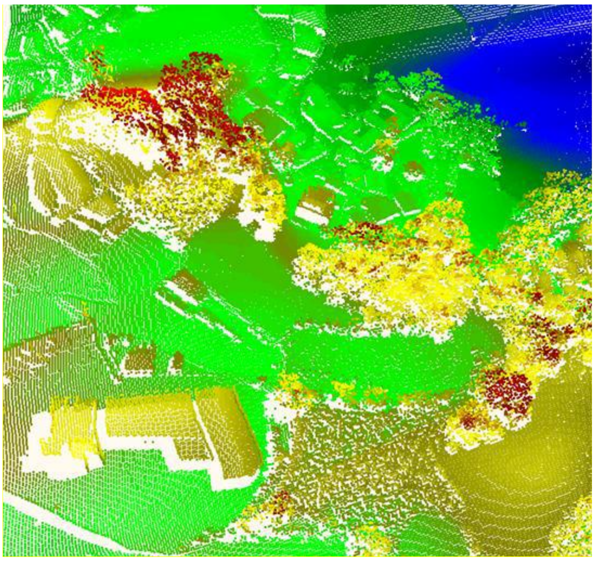

Figure 4: Georeferenced LiDAR data (Choi & Lee, 2011)

Efforts are currently underway to assess the potential of using LiDARs in analysing the technical condition of levees (Bakuła et al., 2016). Advantages include the non-invasiveness of the method (safety of control in the context of ongoing flooding). Already performed experiments prove the high potential of Aerial Laser Scanning data acquired from UAS platforms that deliver products of several centimetres’ accuracy, comparable with the direct measurement techniques.

4.1.3. Radar

UAS that are equipped with radar systems can be particularly useful in situations where access to the location is difficult or dangerous for SAR teams, e.g., in SAR operations when debris and other substances cover an area where people are buried. A drone with a radar system enables the safety of personnel in hazardous environments because people can be positioned in a secure location while the drone is monitoring the terrain.

Ground penetrating radars (GPR) on UAS need to be steadied and flown close to the ground to provide high fidelity data from spots that are of interest such as collapsed buildings, avalanches and mudslides runout zones (Camara, 2014). In the EU funded project CURSOR, for instance, a GPR drone was developed to detect survivors buried underneath rubble. Even though the project description envisages to use the GPR as a sensor on board of the drone, this was not done in the field trials. The GPR was transported by the drone in a

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container and lowered remotely via a controlled electric winch (Ristmae et al., 2021). Why the project opted for this arrangement was, unfortunately, not explained in the information published.

Figure 5: Ground Penetrating Radar Drone (GPRD) of the CURSOR project (Ristmae et al., 2021)

4.1.4. Chemical and electrochemical sensors

Chemical and electrochemical sensors are most commonly used for detecting hazardous materials, toxic gases, or chemical leaks in disaster areas. In the quick poll (n=9), two participants said that their organization is using chemical sensors in their work and two more would like to use them in the future. UAS equipped with chemical sensors ensure the safety of emergency personnel on the ground as the extent of chemical contamination can be assessed without people having to enter the area in question. Detecting chemical contamination can also be beneficial for decision-making in SAR operations when people need to respond to an industrial accident. If hazardous material is identified, these areas will be prioritized for SAR to limit the contamination of victims.

UAVs equipped with chemical sensors can also be helpful for firefighting purposes as they can detect flammable or combustible gases. By identifying potential fuel sources or chemical hazards, these sensors assist in assessing the risk level, planning containment strategies, and enhancing the safety of responders.

Chemical sensors can also be employed to monitor critical infrastructure such as pipelines, storage tanks, or chemical plants during and after disasters. By detecting leaks or releases of hazardous substances, drones equipped with chemical sensors contribute to the early detection of potential threats and facilitate timely repairs.

4.1.5. Searchlights

In the quick poll, two participants indicated that they are using search lights as auxiliary support systems for UAS and one more would like to use them in the future. The connected practices for using search lights as an auxiliary support system on drones are quite straight forward. Searchlights enable the usage of the UAS during the night and in low-light conditions so the UAS can continue to be the "eye in the sky", especially when other low-light-operating sensors are not available. Hence, search lights are particularly interesting for organisations that predominantly use UAS and RBG cameras in SAR operations.

However, several non-standard usages of searchlights were mentioned as well: they can serve as a beacon for the fast indication of a point of interest (e.g., in a casualty) to personnel without other localization aids. Search lights were also used to light the path for stranded rock climbers or as temporary floodlight for rescue activities (in this case for the deployment of the primary battery-driven telescopic floodlights).

4.1.6. Loudspeakers

Similar to microphones, a UAS equipped with a loudspeaker might not be a first choice when it comes to auxiliary support systems for disaster management. However, there are practices of disaster management where mobile loudspeakers can be very efficient. First and foremost, loudspeakers are used to communicate information. In a disaster situation, firefighters and other emergency services use sirens and loudspeakers to warn the public and distribute instructions how to proceed and which protective actions to take. Traditionally, this is done by driving through the streets with an emergency vehicle that is equipped with loudspeakers, dissemination of information through media such as radio and television, and using warning apps and/or cell broadcasting to reach people via their mobile phones. In a scenario where roads are not easily accessible, in remote areas, or in areas with disrupted infrastructure (e.g., during a blackout where radio and television are not working), a UAS with a mounted loudspeaker could be an effective tool to reach the affected population quickly and thoroughly. In the quick poll, one participant declared to be using a loudspeaker, while one more participant wishes to use a UAS equipped with a loudspeaker in the future.

In medical emergencies or SAR operations where survivors are found via UAS, but rescue personnel have not reached them yet, loudspeakers on UAS can offer early communication to reassure them that help is under way. In mountain rescue trials using these systems, participants reported that “they felt immediate relief upon drone arrival, being calmed down by the rescuers who were able to send them relevant information via the loudspeaker system. In this regard, the sound of a human voice is preferential to simple visual light signals.” (Wankmüller et al., 2021, p. 9).

4.1.7. Delivery Platforms

Delivery platforms were the auxiliary support system that received the most attention in the quick poll. Only one participant indicated that their organization is already using them in their work. However, four more participants wish to establish them in their disaster management practices in the future. Delivery platforms for UAS are used in various capacities within the field of disaster management. For instance, they can be applied in the supply of medicine and aid delivery. Delivery platforms for UAS enable the transportation of essential medical supplies to disaster-affected areas - such as first aid kits, medications, vaccines, blood units, or diagnostic equipment. Drones can swiftly deliver these supplies, particularly in hard-to-reach or inaccessible locations where traditional transportation infrastructure may be damaged or impassable. Essentially, everything that is needed in an area affected by disaster and everything that is light enough could be transported via a UAS. On the one hand, this might be communication equipment such as satellite phones, radios, or Wi-Fi devices, to restore or establish communication networks. On the other hand, it might be emergency kits (including blankets, tents, and hygiene items), or clothing, life jackets, ropes, and rescue buoys, to aid rescue operations and to provide temporary relief and support for displaced individuals or those affected by the disaster. Rescuers participating in the COLLARIS workshop in Sweden, 2024, also point to the great potential of drones with significant payloads (up to 30kg) to quickly carry heavy tools, for example, during USAR operations.

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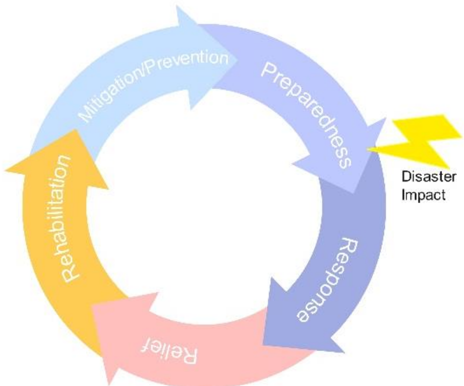
In situations where access to food and clean water is disrupted due to a disaster, drones equipped with delivery platforms can transport food packages, nutrition supplies, or water purification kits to affected populations. This helps ensure immediate access to basic necessities in areas where conventional delivery methods are hindered. In scenarios that involve chemical spills, hazardous materials, or disease outbreaks, delivery platforms on UAS can transport sample collection kits or diagnostic tools to gather specimens for analysis. This can facilitate a rapid and accurate assessment of environmental or biological hazards without putting emergency responders at risk.

In the EU funded project CURSOR, for instance, delivery platforms on UAS were used to transport so-called “SMURFs”, small, agile robots that are equipped with loudspeakers, microphones and cameras to search for missing people in rubble caused by earthquakes (CURSOR, 2020).

In Västra Götaland County in Sweden, UAS and delivery platforms are used to deliver defibrillators to save lives in cases of emergency calls indicating a cardiac arrest. Survival rates of cardiac arrest are quite low with 10% and the chance of survival decreases by 10% per minute. Surviving a sudden cardiac arrest requires immediate action in the form of CPR and shocks from a defibrillator. CPR and early defibrillation can more than double the chances of surviving a cardiac arrest. In a feasibility study, five drones with a 6 km-radius range were situated within the controlled airspace of two airports, covering approximately 200,000 inhabitants in Sweden during the day. The drones were adapted with a winch system for the delivery of a defibrillator. On the scene, the UAS hovers 30 meters above ground, releases the defibrillator down with a wire, and then flies back to base. Since the start of the project, about 400 flights were conducted with around 115 successful deliveries of defibrillators which counts for a 30% application rate. The application of the UAS with a delivery platform resulted in quicker response times. More than 60% of the time, the UAS arrived at the scene before the ambulance. It is now a fully operational system that is seamlessly integrated in the alarm chain. However, due to current aviation law in Europe, such use is enabled by employing it inside a CTR area (volume of controlled airspace, usually situated below a control area – such as an airport).

4.2. Rehabilitation/Recovery



RGB-cameras are also frequently used for post disaster damage assessment to get an overview of the situation from above. Cameras on drones provide a visual documentation of disaster-affected areas which allows for a rapid and comprehensive damage assessment. High-resolution images and videos captured by UAS help emergency management teams to assess the extent of structural damage, infrastructure failures, or other impacts caused by disasters.

In the post-disaster phase, thermal imagery can also be utilised in the rapid assessment of affected areas. By identifying temperature variations, sensors can help experts to assess the structural integrity of buildings, identify potential hazards, and evaluate the extent of damage caused by disasters like earthquakes, floods, or hurricanes (Loerch, 2022). A bit uncommon, but possible, is also the use of thermal imagery for the detection of shallowly dug items: shallow dug mines or scattered mining (mines ejected from flying canisters) (Shimoi, 2013) or other buried items (e.g., forensic investigation or search for illegally disposed canisters with hazardous materials) are a potential application of thermal imagery.

Participants of the quick poll also provided connected practices to the use of multispectral cameras in crisis and disaster management. One practice is the index calculation of burned forests after a wildfire. Hence, multispectral cameras are used in this case in the recovery phase of a crisis or disaster to assess the damage of the incident. Multispectral cameras on a UAS provide a solution to cover a large area quickly without having to deploy more expensive systems such as a helicopter or having to compare current pictures with pictures made before the incident in case of solely using RGB-cameras (Shin et al., 2019).

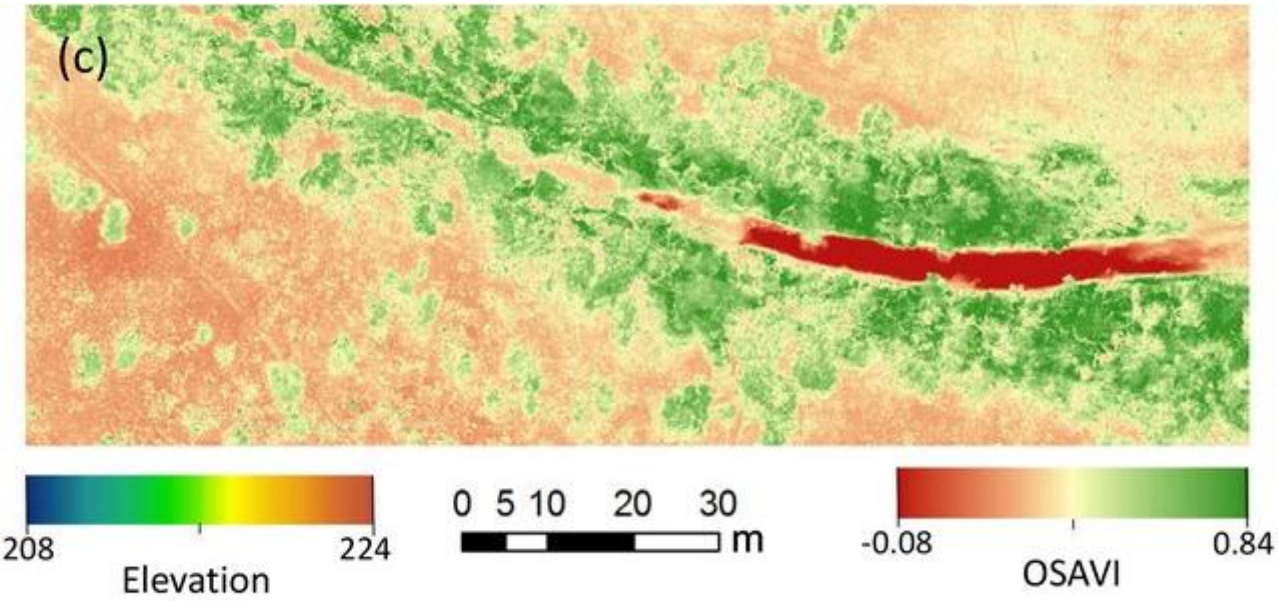


Figure 6: Optimized soil adjusted vegetation index (OSAVI) derived from the 4-band multispectral image (McCabe et al., 2017)

For the identification and mapping of landslides, drones equipped with LiDAR can be deployed (Giordan et al., 2018). For better results and comparability, a scan of the area before a geological hazard occurs is regarded as highly advisable. This, however, oftentimes does not take place because of high costs, especially for individual landslide studies (Giordan et al., 2018).

4.3. Prevention and preparedness

In wildfire management practices, LiDAR technology can be used in the prevention phase of wildfires to map the canopy fuel attributes needed for wildfire predictions, e.g., to create models with information on canopy cover, canopy height, canopy base height, and canopy bulk density (Moran et al., 2020).

5. Advantages and Disadvantages of the different auxiliary systems

5.1. RGB-Cameras

A UAS equipped with a camera is the most frequent choice of auxiliary support system as it is often enough to meet the goals of an operation. The added value of drones is oftentimes only seen as the “eye in the sky” to improve the situational awareness picture and, therefore, a camera is the most easily accessible and attainable auxiliary support system – it is basically the reason why most organizations acquire a UAS.

Nevertheless, camera sensors come with their limitations. Photographic images are vulnerable to ambient light conditions such as high-contrast light conditions where bright sun is reflecting on the terrain (e.g., on rocks), and in low-light conditions it is improbable that they are effectively aiding disaster management. Depending on the area and reason of deployment, other visual sensors can be used, such as thermal imaging cameras, radar or LiDAR. However, carrying all these sensors on board is infeasible since they are currently still too heavy and expensive. Therefore, in the following section, we set out the most commonly used auxiliary support systems apart from cameras and their uses in disaster management.

5.2. Thermal imaging cameras (infrared)

The most prevalent advantage thermal imaging cameras entail is the enhanced visibility compared to RGB cameras. Thermal imaging cameras can detect heat signatures, allowing drones to see through smoke, light fog, dust, and darkness. This capability is especially useful for locating potential survivors and identifying fire hotspots and allows drone operators to assess potentially hazardous areas from a safe distance. By minimizing the need for personnel on the ground, UAS equipped with thermal imaging cameras can reduce the risk for responders and expedite rescue operations.

On the downside, thermal imaging cameras can be expensive, especially high-resolution and long-range models. This cost may limit the availability of thermal-equipped drones in disaster management operations, particularly in resource-constrained situations. Different forms of isolation (e.g., insulating clothing or obscuring barriers) can reduce the contrast of the object or hide it completely. This property makes infrared sensors less suitable for SAR in dense forest terrain.

Thermal imagery can be misinterpreted, leading to false positives or negatives. Environmental conditions, reflections, or objects with similar heat signatures can impact the accuracy of thermal imaging, potentially affecting SAR efforts. The thermal sensors are sensible instruments and need to be handled with care. If not properly cared for, the sensor can be permanently damaged which will distort the images (DJI, 2023). Furthermore, adverse weather conditions, such as heavy rain or snowfall, can affect the performance of thermal cameras. Precipitation can interfere with heat detection, reducing the effectiveness of the thermal imaging capabilities of the drone. Generally, a certain amount of knowledge of impeding factors for the precision of the thermal images is necessary.

For night vision cameras, it is important to consider that the technology achieves poor results at twilight and dusk. Additionally, strong light blinds the night vision camera. Its contrast, hence, the distinguishability of objects, is the result of the light they reflect. So, dark objects against a dark background will not be visible.

To decide whether a thermal camera will be beneficial, first, an assessment is needed if the sensor in question fits the current or planned practices. The UAS weight carrying capacity, battery life, as well as financial resources need to be considered.

5.3. Multispectral cameras

The imagery across multiple spectral bands enables the detailed analysis of various environmental factors, including vegetation health, water quality, and land cover, which leads to a more comprehensive understanding of the situation. Multispectral imagery collected by UAS can facilitate advanced mapping and analysis techniques, such as vegetation indices, land cover classification, or change detection. These tools help in quantifying the impact of the disaster, identifying areas requiring immediate attention, and supporting long-term planning and recovery efforts (Gutro, 2015).

However, multispectral cameras for UAS can be relatively expensive compared to standard visual cameras. The cost of the camera system itself, along with any additional processing or analysis software, may pose budgetary constraints for some organizations involved in disaster management. Additionally, the analysis of data requires specialized processing and analysis techniques to derive meaningful insights. This necessitates specific expertise or additional software tools, adding complexity to the data processing workflow. As with any auxiliary support system, adding more systems impacts the duration of flight time as they require more energy and shorten battery run time of the UAS.

5.4. Laser scanner / LiDAR

In the context of landslides, LiDAR UAS facilitate a rapid identification of instabilities over an area of several km². Hence, the use of LiDAR UAS for a quick deployment in the response phase after a landslide event is highly valuable when a fast overview of the situation, e.g., blocked roads that hinder rescue operations, is necessary. However, if the affected area is covering several hundred km², other methods - such as using satellite data - might be favoured because flying over an area this large with UAS takes up too much valuable time (Antoine et al., 2020). During forest fires, LiDAR does not necessitate line-of-sight observation of the flames which other surveillance methods such as visible or infrared imaging do. LiDAR interacts with smoke and, therefore, could be a beneficial tool for fighting forest fires quickly (Utkin et al., 2011). Another advantage is that it can be operated during the day as well as during the night. LiDAR systems require little to no external light which means they can be deployed during the night in emergency situations.

A detriment of the system, however, is its weight. LiDAR sensors are often heavy and paired with multiple cameras. This means that, firstly, a UAS with a large enough payload is necessary to carry the sensor, and, secondly, that battery and flight times are reduced due to the weight. To obtain usable 3D models, an additional software is necessary that might not be self-explanatory and easy-to-learn. Therefore, specialised, LiDAR-trained personnel are crucial to be able to use the collected data efficiently.

5.5. Radar

In situations where infrared or LiDAR systems do not suffice because "sensing modalities are limited by debris and building materials that cover or occlude the victim at the disaster site" (Rong et al., 2021), selecting radar or more specifically GPR might be a good choice. Radar systems provide UAS with the ability to detect and track objects and terrain features even in low-visibility conditions such as fog, smoke, or darkness. This enhanced situational awareness enables effective disaster response and management. Radar systems can also cover large areas efficiently, allowing drones to monitor vast disaster-affected regions quickly. This capability aids in identifying critical areas, optimizing resource allocation, and improving emergency response times.

As a downside, the costs of radar systems should be mentioned. They are relatively high compared to other sensing technologies. To equip drones with a radar system may significantly increase the overall cost of the drone and its operations, making it less accessible for some disaster management organisations. Additionally, radar systems are heavier than other sensors, and their power requirements are higher. This added weight and power consumption reduces the flight time and payload capacity of drones, limiting their operational range and effectiveness. Radar data processing and interpretation can also be challenging, since that requires specialized expertise. Analysing large volumes of radar data collected by drones may pose a bottleneck in real-time decision-making during disaster management. Lastly, while radar systems can provide valuable information, they generally have lower resolution compared to optical sensors. Fine details or specific object identification may be more challenging with radar data, potentially limiting its utility in certain scenarios.

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5.6. Chemical and electrochemical sensors

UAS equipped with chemical sensors can be deployed quickly in disaster-affected areas, providing immediate data collection and analysis. They provide real-time data on the presence and concentration of gases or hazardous substances in disaster areas. This enables faster response times and helps emergency responders make informed decisions without risking the safety of personnel in potentially hazardous environments. Additionally, UAS equipped with chemical sensors can cover large and/or difficult to access areas efficiently which allows for a comprehensive understanding of the extent and impact of chemical hazards.

Nevertheless, chemical sensors also come with disadvantages. They might have limitations in terms of the detection range and sensitivity to certain gases or substances. Some sensors may not be able to detect low concentrations of chemicals, or they may have limited detection capabilities for specific compounds. They also require regular calibration and maintenance to ensure accurate readings. Calibrating and maintaining the sensors can be time-consuming and may require specialized knowledge or equipment. Besides that, the interpretation of data collected by the sensors can be challenging as it often requires expertise in understanding gas concentrations, exposure limits, and potential health risks. Adequate training and data analysis tools are necessary to make informed decisions based on the collected data. External factors may affect the dispersion of gases, making it more challenging to pinpoint exact locations or assess the extent of the hazard accurately.

Last but not least, chemical sensors for drones can be expensive, particularly those with advanced features or capabilities. The cost of acquiring and maintaining the sensors as well as integrating them with drone platforms may be a limiting factor for some organizations.

5.7. Searchlights

The primary advantage of using a searchlight on an UAS is the already mentioned improved visibility during low-light conditions or the night. Therefore, searchlights can extend the timeframe in which SAR operations can be carried out (which in most cases means operating during night-time). By providing illumination, the searchlight allows drones to continue their missions when natural light is insufficient, increasing the operational time and overall efficiency of the drone in disaster management scenarios. Searchlights are also quite versatile payloads that can be easily integrated into drones with appropriate mounting systems. They can be adjusted and directed in various angles and positions, allowing for flexibility in illuminating specific areas or targets of interest during disaster response operations.
However, adding a searchlight payload to a drone increases its overall weight which can have a negative impact on flight performance. The additional weight can reduce the drone's flight time and operational range, limiting its effectiveness and requiring more frequent battery swaps or recharges. Hence, the drone's weight restrictions and payload capacity must be taken into consideration, especially when several sensors are to be deployed in a crisis situation.

Hence, one needs to consider what kind of purposes the payload should be deployed for and if other sensors might provide better solutions, e.g., radar or infrared cameras. However, searchlights are considerably cheaper than other sensors that allow good visibility at night and, therefore, might be a good solution if financial resources are a restricting factor.

5.8. Loudspeakers

UAS equipped with loudspeakers can broadcast important information and instructions to affected populations during disaster situations. This enables emergency management authorities to provide real-time

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updates, evacuation notices, safety instructions, or other critical information to a large number of people quickly and efficiently, especially in areas that are otherwise hard to reach. The UAS can reach remote or inaccessible locations, including areas where communication infrastructure may be damaged or unavailable. This allows for effective communication in areas where traditional communication channels are compromised. Another benefit would be to disseminate the information in different languages to reach vulnerable populations that might not speak the official language of the country and who are often excluded from traditional warning communication. For the communication with individuals, e.g., in mountain rescue, the method of dropping a handheld two-way radio with a drone can be used, allowing to sustain continuous two-way communication.

A drawback of loudspeaker systems is that they can be affected by environmental factors such as wind, background noise, or the distance between the drone and the target audience. Sound quality may vary, especially in noisy or crowded environments, reducing the effectiveness of the message delivery. Due to the nature of drone operations and flight time limitations, the duration of the messages delivered by loudspeakers may be relatively short. This can restrict the amount of information that can be communicated in a single pass which might require multiple drone flights for more extensive or detailed messages.

While UAS equipped with loudspeakers can deliver messages in multiple languages, challenges may arise in communicating with individuals who are unfamiliar with drone operations or who have limited understanding of the messages due to language or cultural barriers. However, this is true for any form of warning communication. In the context of UAS operations, however, trust in the source of information might be a factor that could impede the effectiveness of communication. If it is not clear who is communicating through the UAS, individuals might not trust the information and might not act accordingly.

5.9. Delivery Platforms

Delivery platforms enable quick and efficient transportation of essential supplies and equipment to disaster-affected areas. UAS can navigate through challenging terrain or bypass damaged infrastructure, ensuring rapid delivery of critical resources, aid, or equipment. Generally, delivery platforms are customizable, allowing for the transport of various types of payloads based on the specific needs of the disaster response. They can be adapted to carry medical supplies, food packages, communication equipment, or other necessary resources, providing flexibility in meeting the evolving needs of the situation. The use of delivery platforms for UAS enhances safety by minimizing the risk to ground personnel during the transportation of supplies in hazardous or unstable environments. UAS can access disaster zones, including areas with collapsed structures, flooding, or chemical hazards, reducing human exposure to potential dangers.

Nonetheless, delivery platforms have payload limitations based on the drone model used and depending on how the platform is designed. These limitations restrict the size, weight, and volume of the cargo that can be transported. Large or heavy items may exceed the payload capacity of the UAS and cannot be transported via the delivery platform. Furthermore, UAS have limited flight ranges and endurance due to battery limitations. This can restrict the distance over which delivery platforms can effectively transport payloads. Longer distances may require multiple drone flights or the use of additional charging or docking stations.

Adverse weather conditions such as strong winds, rain, or snow can impact the flight capabilities of drones and the safety of payload delivery. In most cases, the UAS will not be able to fly and transport the cargo under these circumstances. Additionally, the use of delivery platforms for UAS (or UAS in general) in disaster management is subject to local regulations and airspace restrictions. Compliance with regulations related to flight permissions, payload weight restrictions, or specific operational requirements can impact the deployment and effectiveness of delivery operations.

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6. Recommendations and conclusions

Options for auxiliary support systems for UAS in disaster management are manifold and cannot be portrayed all-embracingly in this report. Therefore, the currently most commonly used systems were described as well as the ones prominent in scientific literature and systems that were mentioned by participants of a quick poll.

Overall, the use of auxiliary support systems depends on the established practices that the organisation wants to enhance with a UAS. Due to their high price ranges (depending, of course, on the system) and depending on the capacities of the UAS (e.g., battery run time that is shortened the more auxiliary support systems are mounted on it and used, or weight carrying capacity), it should be carefully considered which auxiliary support system is of best use for the tasks at hand. This is true especially for the different camera systems that all provide a visual but with different foci. Hence, it is important to consider which data needs to be collected by the UAS, and if the data also can be analysed adequately by trained personnel. Furthermore, the personnel should be knowledgeable about pitfalls of the systems to be able to assess their quality.

All systems presented have their advantages as well as disadvantages, and their usage should be well practiced by the disaster management actors to be most effective.

RGB-Cameras:

- Cameras are the most frequently chosen auxiliary support system due to their ability to improve situational awareness.
- They are the primary reason for most organizations acquiring UAS.
- However, cameras have limitations in high-contrast and low-light conditions.

Thermal Imaging Cameras:

- Provide enhanced visibility by detecting heat signatures, useful for locating survivors and identifying fire hotspots.
- Reduce the risk for responders by minimizing the need for ground personnel.
- Can be expensive and sensitive to environmental conditions, requiring careful handling and knowledgeable operators.

Multispectral Cameras:

- Enable detailed analysis of environmental factors, aiding in disaster impact assessment and long-term planning.
- Require specialized processing and analysis techniques, which can add complexity and cost.

LiDAR:

- Useful for rapid identification of terrain instabilities and assessing forest fire situations.
- Can operate both day and night without needing external light.
- Heavy and complex, requiring specialized personnel and additional software for data interpretation.

Radar:

- Effective in low-visibility conditions and for detecting and tracking objects and terrain features.
- Can be expensive and heavy, with complex data processing needs.
- Lower resolution compared to optical sensors.

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Chemical and Electrochemical Sensors:

- Provide real-time data on hazardous substances, aiding in quick and safe emergency responses.
- Require regular calibration, maintenance, and specialized expertise for data interpretation.
- Can be expensive and affected by external factors like gas dispersion.

Searchlights:

- Improve visibility in low-light conditions, extending the operational timeframe of UAS.
- Are cheaper compared to other night-vision technologies but add weight and consume a significant amount of energy, affecting flight performance.

Loudspeakers:

- Allow for broadcasting critical information to affected populations quickly and efficiently.
- Sound quality can be affected by environmental factors, and the duration of messages may be limited by drone flight time.

Delivery Platforms:

- Enable quick transportation of essential supplies to disaster-affected areas, enhancing safety by reducing human exposure to hazards.
- Have payload limitations and are affected by adverse weather conditions and regulatory constraints.

General Recommendations:

- **Assess Fit for Current or Planned Practices:** Evaluate whether a sensor aligns with the specific needs of the operation.
- **Consider Weight and Battery Life:** Ensure that the UAS can carry the sensor without significantly reducing flight time.
- **Budget Constraints:** Balance the benefits of advanced sensors with their costs and the available financial resources.
- **Expertise and Training:** Ensure operators are trained to handle and interpret data from specialized sensors.
- **Regulatory Compliance:** Adhere to local regulations and airspace restrictions to ensure safe and legal operation.

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