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USING DRONES IN SUPPORT OF RESCUE INTERVENTIONS TEAMS IN TOXIC/FLAMMABLE/EXPLOSIVE ENVIRONMENTS

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Abstract

Intervention and rescue activities require knowledge of the real situation in the affected area as accurately as possible. Therefore, the physical exploration of this area is at the same time necessary and risky.

The use of drones from a safe distance can protect the intervention team from exposure to unknown hazards. Endowment of the drone with a suite of sensors such as high resolution cameras, thermal imaging, infrared, and gas detection equipment permits vital data to be transmitted to the base of intervention. Hazardous areas can be studied from different angles, from an altitude that provides a panoramic view, and make available rescuers information about dangers encountered, state of access routes, number of people caught by the event, and control or protective measures that need to be taken.

The current paper presents the methods for use and control of drones in support of rescue actions, resulting from tests performed by the research team, trained and certified to use drones, within the National Institute for Research and Development in Mine Safety and Protection to Explosion – NIRD INSEMEX. It was demonstrated that a drone which carries a multigas detector and a high definition video camera can help rescuers which intervene in an area with fire/toxic/flammable hazard. For such a mission, a drone must be capable to flight a long time, to carry the multigas detector and to flight secure without visual contact and without autonomous flight support in case of GPS signal lack. Flights in such conditions impose high power engines with 6-8 propellers for fine adjustments.

Key words: dangerous areas, drone, intervention and rescue personnel, tests, toxic/flammable gases

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1. Introduction

NIRD INSEMEX is a founder member of International Mines Rescue Body (IMRB) and participates in biannual conferences where news about mining rescue is presented. The IMRB is an informal association representing mine rescue organizations from around the globe (UIA, 2010). The purpose of the IMRB is to promote mine rescue operations at the international level and to improve mine rescue knowledge and practices through global cooperation, to promote the exchange of information between the mine rescue services of different countries. In intervention and rescue activities in toxic/ explosive/ flammable environments, reaction time can make a difference especially when it comes to saving human lives. Worldwide, rescue activity from potentially explosive, toxic, flammable environments involves four unanimously accepted principles (Găman et al., 2017):

- ensuring the safety of self and rescue team;
- endeavouring to rescue or ensuring the safety of trapped or injured workers;
- protection of the economic unit property from further damage;
- rehabilitation of the affected work area and salvage of equipment.

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Because of the first principle, it is vital for decision-makers to gather information from potentially dangerous environments, as soon as possible. To this respect, a small flying vehicle capable of performing changes in direction in small spaces, flying to a fixed point and transmitting real-time information from near the dangerous area is the ideal device in such situations. These attributes belong to a type of flight apparatuses that are commanded from distance generically known as drones although because of their lifting power principles are very different. Unmanned aerial vehicles (UAVs) are aircrafts which offer unprecedented spatial resolution and new mapping opportunities at local scale, with various advantages, including: the ability to fly at low altitudes, capturing high resolution images from remote locations, the capability to carry different sensors, the possibility to take pictures from different angles (Giordan et al., 2017). Unmanned aerial vehicles generates lifting power similar to classic airplanes by deviating the air under the wing with the help of engines or by placing the motors horizontally and driving the propellers just like helicopters. The two lifting power principles are used according to needs, having a number of distinctive features:

- airfoils are useful when high travel speeds are required;
- horizontal rotors allow to maintain a fixed point, low speed movements, rapid steering changes;
- airfoils involve lifting in the air either from a plan land that is not always found near the interest area, or launching by a vehicle;
- multi-rotor devices can take off under more difficult environments, requiring a flat surface comparable to the largest distance between the ends of the propellers on the opposite arms.

Given the specificity of intervention and rescue activities, multirotor drones best meet the technical requirements for use in case of a dangerous event. The novelty of the paper lies in the research of theoretical aspects related to multirotor drone's principles of construction, the selection of constructive elements and the launching of a flight apparatus meant to satisfy the requirements of intervention and rescue activities. The research focused on two objectives, namely the construction of a prototype meeting the flight requirements and the design and implementation of a system for measuring the concentrations of hazardous gases and the real-time transmission of the data to ground (Găman et al., 2012). In the past, vehicles were used to collect data and images in intervention and rescue operations, but they were terrestrial or submersible vehicles. Although the use of drones for intervention and rescue activities has been in the hands of other institutions worldwide, the novelty of this project lies in the integration of a monitoring system for hazardous gases into the drone's structure and the transmission of the recorded values to the ground station (Găman et al., 2014; Waren, 2017). The use of such a drone increases the safety of the search team because vital information is obtained without exposing the team to potential dangers, the actual intervention taking place only after the team has gathered the overall images of the event, has become aware of the potential dangers and checked for the presence of dangerous gases in the hazardous area (Pupăzan et al., 2012).

A research presented at IMBR, referred to the use of an underground drone at Russell Vale mine in Australia. The purpose of this research was to test the propagation of drone's video signal and control commands through the underground data transmission network. That project demonstrated that a pilot cannot successfully fly a drone remotely for any length of time utilizing only video signals due to the time "lag" on signal (i.e. the length of time behind "real time" that the pilot is seeing the video footage transmitted by the drone). As a result the pilot is reacting to changes in the environment that have occurred after he actually sees them (Tonegato, 2017). Our research focused on developing a drone capable of carrying out both underground and surface missions specific to intervention and rescue activities in toxic / explosive / flammable environments. There are many similarities between the two fields of activity but also differences, especially related to rescue team's course of action but also to drone's operating requirements. In underground handling the drone is difficult (narrow spaces, the radio signal for drone control is reflected by walls), in surface interventions the drones must be able to cover large areas, in an organized manner, adjusted to objectives.

2. Experimental

The multirotor drone for intervention and rescue was built, its structure consisting of a tubular frame with eight arms made of carbon fiber joined with a central plate. The 700W engines, the 22 Ah accumulator, the autopilot, the GPS system, the telemetry system, the 3-axis gimbal and the video camera are installed on the structure. With the propellers mounted on the frame, the maximum length of the octocopter is 1700 mm, its weight is 9kg, depending on the flight conditions, the time for the mission is between 15 and 25 minutes for a full charged accumulator. For a displacement for a flight, a monovolume car is enough for all parts and accessories. Only one person is required to prepare the drone for the flight and to operate it, but if it is possible for the pilot to be assisted by another person, it would be useful both for the transport of the equipment and for assuring the safety perimeter for take-off and landing. For a long time mission, two or three accumulators can be used given that the replacement of the discharged accumulator and the take-off takes a few minutes and a fast charge of a 22Ah accumulator lasts 22 minutes. Using brushless motors to propel the drones greatly reduces the risk of explosion, the Li-Po battery and materials that allow electrostatic charging being potentially dangerous. Currently, because of technological conditions, the use of complete explosion risk protection is not possible, because the drone's mass would increase considerably and affect its flying ability. In this regard, through future research, we aim to improve the performance of drones in potentially explosive environments.

For take-off, it is necessary to set a safety perimeter around the drone to avoid accidents. The drone must be prepared and positioned for take-off on a flat terrain without trees, cables or other obstacles and a wide opened view to the sky for a better GPS signal. A full charged accumulator must be connected, the propellers must be connected to the brushless motors, and the remote control must be powered on. The drone is controlled by a main unit which included a barometric sensor for altitude measuring, a gyroscope sensor for levelling and an external GPS receiver. When the drone is powered on, the controller search the signal from its remote control, if the remote is found, the controller wakes up the GPS receiver which will search for GPS and GLONASS satellites. The GPS unit has a blue LED which will be powered if at least 8 satellites signal is received. This phase last about 2 minutes and during this process the drone must remain still. The gyroscopic sensor will set up the gimbal and the video camera will be kept in a stable position on x,y,z axes. The operator can adjust the shooting angle from the remote control by tilting the gimbal or using the " yaw " stick which will twist the drone around the z axis. The drone has a telemetry unit which will send the flight parameters to the ground to the FPV(first person view) unit. When the power button is pressed for 3 seconds and all this conditions are fulfilled, the controller will generate a long sound and the propellers will be put on idle speed waiting for the take off command. On the remote unit, 3 flight modes can be selected:

1. "Loiter" mode: The multicopter automatically maintains its current location, orientation and altitude. When sticks are left free, the multicopter retains its position. For good flight performance in this mode, a good GPS location is required, without magnetic interference and with low vibration. Altitude is measured barometrically. The operator can control the multicopter's movement using the control sticks.

2. "Altitude hold" mode: The multicopter maintains constant altitude. Roll, Pitch, and Yaw functions are manually controlled.

3. "Stable" mode: Operator maintains altitude, speed and orientation control. If sticks are left loose the multicopter does not maintain its position or altitude, it only returns itself to horizontal. Stick controls must be smoothly operated, rough manipulations that may unbalance the multi-rotor are not recommended during the flight.

The "Stable" mode must be used if the mission takes place indoor, underground or between high obstacles where the GPS signal is missing or is poor. This mode is the only one that allows to arm the drone without GPS signal. If the mission involves gases monitoring, prior to the take-off procedures, the X-am 5000 multigas detector must be fixed on the drone and powered on. If the GPS signal is available and an internet connection for satellite data, autonomous missions can be planned using "Mission Planner software". This flying mode offers high precision regarding the geographic coordinates, the pilot must take care only about obstacles that may be in the way of the drone by setting up a proper altitude to avoid them (Sato and Daikoku, 2016). Mission Planner can create missions on itself, which represents an advantage for mapping missions (for example) when the multicopter has to go back and forth on a default pattern ("Auto Grid" function) to check gases. The dialog boxes permit to define altitude and distance between points and the time to hover above each point. Another autonomous mission can be planned using "Loiter Time". The multicopter will fly to the indicated point where it will remain for a specified number of seconds. If the intervention occurs in an area with potential explosive gases, the displacement of the drones will be done at low speed to immediately detect their presence. Although by the drones construction there are no parts generating sparks, electrostatic charge is possible and in order to reduce the risks, it is advisable to proceed cautiously, providing a time of at least 15 seconds for hovering in each investigated point. In the event of a disaster, involving intervention and rescue teams from a potentially toxic, explosive, flammable environment, assisted by the drone, it is advisable to charge as many accumulators as possible during the displacement with the intervention car. With a full charged LiPo accumulator ready for use, the pilot can prepare the drone for the flight in less than 5 minutes. During the flights, discharged accumulators are charged at high charge rate and so the flight duration is maximized. After the end of the mission, the accumulators are discharged to the storage voltage to prevent their damage by the release of gases inside the packaging.

The integrated system (drone-gas monitoring system) has been tested both on the surface (NIRD INSEMEX) and underground (Praid Salt Mine). For real support in the intervention and rescue operations, the measurements performed by the multi-gas detector must be transmitted to the ground station in order to detect possible sources of explosion or fire hazard. The values measured by the multi-gas detector, placed at the bottom of the drone, near the center of symmetry of the rotor axes, are different from the static measured values in that point, the measurement error being influenced by gas density, atmospheric currents and currents generated by the drone. In order to be able to keep the drone in the air for as long as possible, reception and retransmission equipment has to be as light as possible (Găman et al., 2017).

2.1. Testing within NIRD INSEMEX training facility

NIRD INSEMEX training facility has a free circular platform (Fig. 1) about 15 m in diameter, ideal for use as a takeoff and landing point for the drone. Here the drone's flying ability and stability in moderate wind conditions, piloting in "first person view" mode and the use of "mission planner" software for autonomous missions were tested. As a result of the flights performed, the necessary inspections needed to be performed prior to takeoff as well as the order of flights were established. Installations and buildings on the surface of the training facility are useful for training the staff working with drones, in order to increase the ability of maneuvering the drone among the obstacles and of aerial filming.

Fig. 1. View of the landing area of NIRD INSEMEX training facility from the drone

Fig. 2. XAM 5000 multi-gas detector

Gas Detection is performed using the X-am 5000 multi-gas detector made by Draeger (Fig. 2) designed for explosion-hazardous areas or for mining operations where mine gases, classified by zone 0, 1 or 2 may be present. The device can simultaneously monitor five gases: O_2, CO, CO_2, H_2S, LEL. This are standard sensors for the multi-gas detector but the detector can be customized by NO_2, NH_3, SO_2, PH_3, HCN, Cl_2 sensors which can be find out in the X-am 5000's manual. For a particular combustible gas which is possible to appear in the investigated area, the LEL (Lower Explosive Limit) sensor must be calibrated according to the explosive range specific for each gas. For safety reasons, the level of flammable gases must be below 10% of LEL prior to explore a confine space. The reading is performed every 3 seconds and the Gas Vision software synchronizes the detector and mission start times so that the position of the drone is known at each moment, and gas concentration corresponding to the given position can be read (Călămar et al., 2017). For a better detection, given that the response time of the X-am 5000 is at least 10 seconds, a slow speed flight at approaching the disaster area is recommended.

Three test sessions within the NIRD INSEMEX training facility to test the drone operation and data transmission were performed, each with a duration of approximately one hour. During all flights, the drone overflew the installations within the training facility in which explosion-hazardous gases are used, in order to detect possible leakages in the atmosphere. In order to check the gas monitoring system and the ground transmission of recorded values, testing in the training facility within NIRD INSEMEX included the release of methane (CH_4) from a standard cylinder into the atmosphere, the drone being directed to the proximity of the source (Fig. 3), permanently monitoring the values transmitted by the multi-gas detector (Ghicioi et al., 2017). The multi-rotor was kept in flight at a fixed point, so the air currents generated for the load were minimal and allowed detection of released methane. In order to safely conduct the test, the XAM 5000 multi-gas detector was permanently visually monitored, to observe the possible triggering of the optical and acoustic alarm when reaching the first hazard limit, respectively 10% of the lower explosive limit, in which case the drone would have been quickly removed from the gas source.

Fig. 3. Measurements with the gas detector on the drone located near the source

A series of flights were then conducted over this source on 3 height-adjusted platforms automatically maintained and with horizontal movements of approximately one-meter radius from the gas source. The solution of using the multi-gas detector (XAM 5000) was chosen due to the possibility of its configuration with 1-5 gas sensors that can be selected by the user, its reduced mass of only 220 g and because of the possibility of real-time transmission of recorded values by means of its own IR modem. In order to transmit the data packets gathered from the multi-gas detector, a Raspberry PI

III module was installed on the drone, to which the XAM 5000 detector's IR modem was connected by a USB port. Since the compilation mode of the Gas Vision software does not allow running under Linux platforms and the Raspberry PI III processor is an ARM-restricted processor, hardware and software compatibility has been achieved by making a virtual Windows 10 IOT operating system with the use of Wine and Exegear software in the Raspbian virtual environment (Vlasin et al., 2014). Considering that the data packets transmitted by the gas detector are small and the reading interval is three seconds, the 1GB RAM and the four-core processor of the Raspberry PI III computer are enough to cope with the data transfer through the two programs running on two operating systems based on different platforms. In order to prepare the drone to transmit data to ground, it is necessary to connect the Raspberry PI III module to the flight monitoring laptop, to run the operating systems, to turn on Gas Vision and the multi-gas detector and to connect by using the Gas Vision measurement function. The data transfer between the Raspberry PI III module and the laptop is performed through a pair of radio modems identical to those used by the drone to transmit on-screen information but configured on a different carrier frequency (Kovacs et al., 2016). After performing the "handshake" type protocol between the two computers, the drone can be sent to the points of interest by being piloted using the on-board images received on the dedicated monitor, and the gas concentration monitoring window can be maintained on the control laptop (Dolev et al., 1983).

2.2. Testing in Praid Salt Mine

During the test program, the following were aimed: the piloting capacity without autopilot support (because in such conditions without GPS signal, the flight between walls depends on the skills of the pilot, the effects of the deflected air stream impose permanent adjustment of the controls), checking the drone response to flying instructions and the gas measurements periodically performed by the multi-gas detector. Three underground flights were carried out at different locations, which had as objective inspecting the structure of ceiling and walls in high areas (20m), inaccessible to be inspected from the floor level, in order to protect workers from rock debris from heights but also to detect any presence of hazardous gases. Fig. 4 shows the drone's lift towards the ceiling of a room of approximately 50x30x20 m, the picture was taken by the ground team.

The analysis performed by the drone showed that one of the explored rooms has numerous stalactites on the ceiling, having a length of 30-40 cm, the thickness at the base being about 8mm (Fig. 5). Although they are easily dislodged from the ceiling, they are not dangerous to workers because of their lightness. The flight was hampered by the pilot's difficult orientation, given that the only light sources were those on the drone and the space vision was limited. The irregular shape of the walls required a low speed travel. The picture was taken with the onboard camera, gallery lightning was switched off and the light came from three LED projectors fitted on the drone.

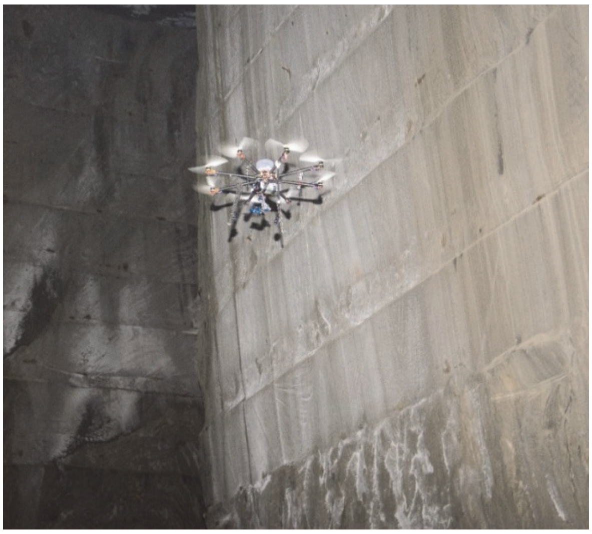

Fig. 4. The drone flight towards the room ceiling

Fig. 5. Stalactite photographed with the camera installed on the drone

3. Results and discussion

Within the NIRD INSEMEX training facility, both the detection of a gas source presenting explosion or fire hazard, as well as the measurement of the gas cloud values, were monitored. At the first test, which implied a fixed flight over the source, values of 4-9% of the LEL were obtained. The purpose of the test was to functionally check the reading-transmission-reception chain of the measurements (Păsculescu et al., 2017). The Gas Vision software is used to receive data and to open logs of previous measurements (Fig. 6). It allows simultaneous display of measured values graphs, highlighting the concentrations of each gas and the moment in time when measurements were performed and activating the function of real-time reading the values measured at 3 second intervals

(Bandopadhyay and Ganguli, 2004; Tomescu et al., 2017).

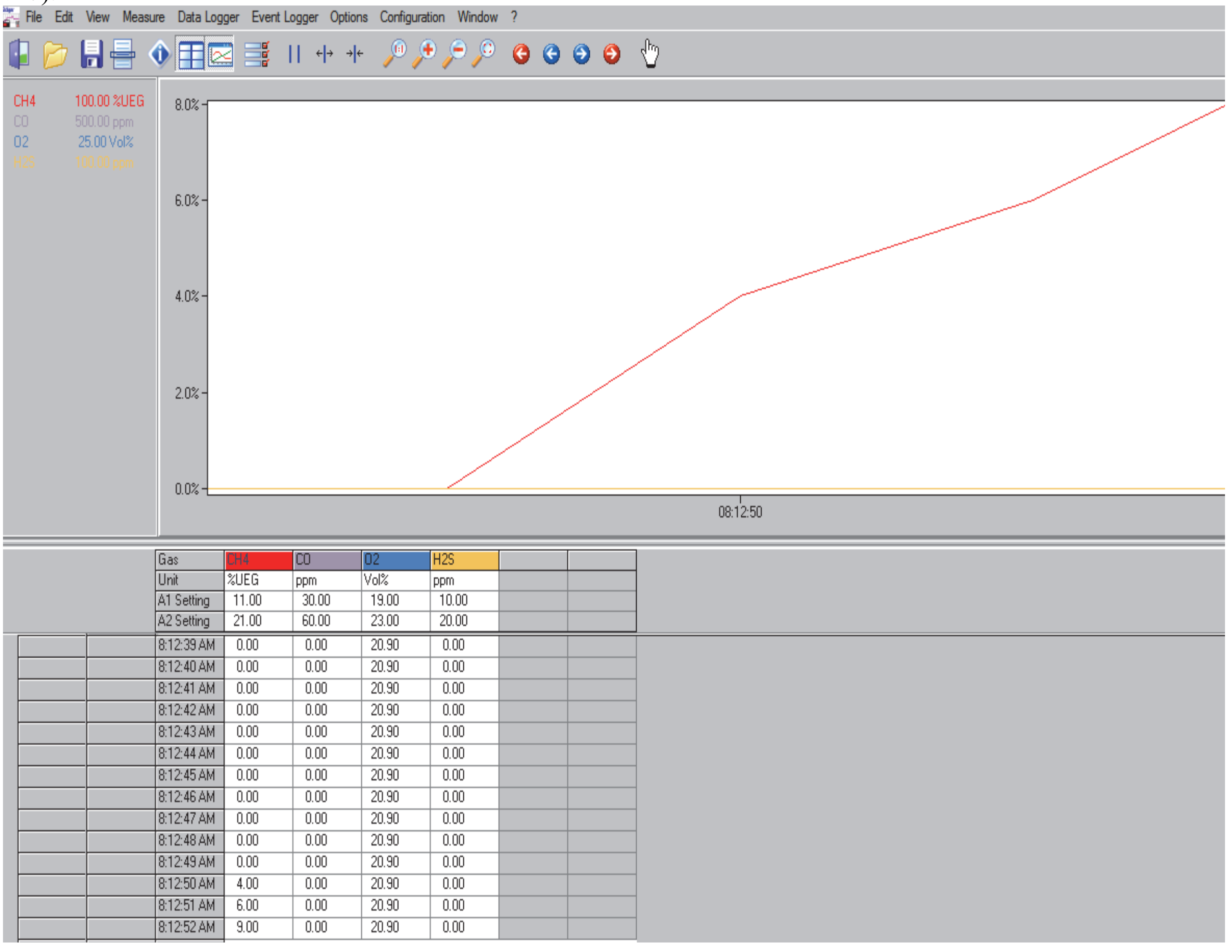

Fig. 6. Screen capture of measurements performed and received in Gas Vision

Table 1. LEL values according to distance

Altitude from the source	***Distance 0 m on radius***	***Distance 1 m on radius***	***Distance 2 m on radius***	***Distance 3 m on radius***	***Distance 4 m on radius***
1	9	6	3	1	0
2	5	2	1	0	0
3	1	0	0	0	0

The results, from the three fixed-height flights, reported as a percentage of LEL, are shown in Table 1. The values obtained were influenced both by the atmospheric conditions and by the turbulence created in oblique plane on the source, by the drone's movement, because, unlike the fixed flight, the horizontal movement command implies slowing down the anterior engines and accelerating the posterior ones which results in a tilt of approximately 30 degrees from the horizontal to allow movement (Kovacs et al., 2014).

4. Conclusions

Tests carried out both in the training facility within NIRD INSEMEX and in Praid Salt Mine have confirmed the support capacity offered by the drone for the intervention and rescue activities, both by using on-site video images and by measuring concentrations of dangerous gases in the atmosphere. This information is extremely useful for the rescue and intervention team entering the dangerous area, because based on this information they can plan intervention to increase safety of all team members.

Using drones in support of intervention and rescue teams can be difficult because of obstacles that can be encountered while traveling, smoke, fire areas, and explosive gases. Under these difficult circumstances, the pilot will have to move the drones as far as possible from the dangerous area to collect data but be able to maintain control over it and keep it on the fly, these skills requiring many hours of training.

Although the drone has 1700 mm diameter on opposite propellers tips, it is suitable for flights in confined spaces because of a fine control on each propeller and the distribution of air streams which conduct to low influence from the deflected air from walls, floor and ceiling. The narrowest tunnel where the flight was stable, with small deviations from hover, had 3.2 m between walls. The ratio between overall dimensions, weight and power allows attachment of other equipment for surveillance, measurement or flight safety enhancement. A small thermovision camera can be attached near the flying camera with an electronic switch allows the pilot to switch the image from the visible spectrum to the thermal infrared to detect injured persons in a smoke-filled environment, LIDAR sensors for collisions avoidance and 3D images of the environment computing etc.

Even if the gas measurements are taken by flight and are not so accurate as an onsite measurement, the information regarding the gas nature and its concentration delivered in real time to the rescuers can be critical for choosing the better intervention procedure and the amount of work estimated for the rescuers.

The ability to perform scheduled flights and hovering over the points of interest for a specified period of time is very useful for determining the proportion of the event and determining the affected area. These data help the rescue station chief to make decisions on the number of rescue teams to intervene, the choice of access ways, the need for intervention materials and the compressed air cylinders for rescuers apparatus. Autonomous navigation software allows the execution of a wide range of scheduled flights, from simple flight command to a point of interest on the map, to surveillance missions through circular flights around it, with the camera permanently focused on it.

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