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# UAV for "safe" NaTech disasters management and consequences evaluation in Major Hazard industrial plants

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The impact of a natural disaster on a facility storing or processing dangerous substances can result in the release of hazardous materials with possibly severe off-site consequences through toxic-release, fire or explosion scenarios. EU regulation, namely Directive 2012/18/EU, among its new elements explicitly requires the analysis of NaTech (natural hazard triggering technological disasters) hazards. Main issue related to NaTech accidents is the simultaneous occurrence of a natural disaster (i.e. earthquakes, floods and lanslides) and a technological accident, both of which require simultaneous response efforts in a situation in which lifelines needed for disaster mitigation are likely to be unavailable. In addition, hazardous-materials releases may be triggered from single or multiple sources in one installation or at the same time from several hazardous installations in the natural disaster's impact area, requiring emergency-management resources occupied with responding to the natural disaster to be diverted. In this paper it is proposed and evaluated the application of dedicated collision tolerant UAV systems for NaTech accident emergency management. The collision-tolerant drone is designed for the inspection and exploration of the most inaccessible places, allowing to fly in complex, cluttered or indoor spaces. By enabling remote visual inspection in any indoor complex and confined spaces environments, it prevents the need for workers to enter hazardous places or face dangerous situations avoiding at the same time the risk of collisions and injuries. The drone is equipped with a collision tolerant carbon fiber protective frame. The integrated payload is represented by Simultaneous full HD and thermal imagery recording, and adjustable tilt angle with leds for navigation and inspection in dark places. Fast connections and data processing allow real time data processing and management of the situation. This methodology represents an effective approach to NaTech disasters management and consequences evaluation.

*Keywords*: NaTech, Unmanned Aerial Vehicles, Major Hazard Industrial Plant, Emergency Management.

## 1. Introduction

Plants that exceed a specific threshold of quantities of hazardous substances, present within the system, are defined as being at risk of a major accident according to Directive 2012/18/EU [1]. The same Directive defines a major incident as: "an event such as a large emission, fire or explosion, due to uncontrolled developments, which occur during the activity of a plant subject to this decree, and which gives rise to a serious, immediate or delayed hazard for human health or for the environment, inside or outside the plant, as a result of one or more hazardous substances". From the above description, the harmful events are emissions, fires or explosions, resulting in a state of emergency for the area surrounding the point of release. In addition to these harmful events, there are also natural catastrophic incidents, that is to say events not ascribable to human action, such as landslides, earthquakes and hydrogeological events.

Recent major natural disasters highlighted the emergence of a new type of risk that manifests itself when the natural and technological worlds collide. The impact of a natural disaster on a facility storing or processing dangerous substances can result in the release of hazardous materials with possibly severe off-site consequences through toxic-release, fire or explosion scenarios. Accidents triggered by a natural hazard or disaster which result in the release of hazardous materials are commonly referred to as NaTech (natural hazard triggering technological disasters) accidents. This includes releases from fixed chemical installations and spills from oil and gas pipelines.

Despite a growing body of research and more stringent regulations for the design and operation of industrial activities, NaTech accidents remain a threat.

The Directive 2012/18/EU of the European Parliament and of the council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, implemented by member states, recognize the relevance of NATECH.

In minimum data and information to be considered in the safety report of major accident industrial plants for that concerns the identification and accidental risks analysis and prevention methods is required a detailed description of the possible major-accident scenarios and their probability or the conditions under which they occur including a summary of the events. which may play a role in triggering each of these scenarios, the causes being internal or external to the installation; including in particular: natural causes, for example earthquakes or floods.

It's also evident, due to the impact of NaTech on major accident scenarios, the relevance of the issue in information to the public; in evaluation of domino effect and in land-use planning and emergency management.

NaTech risk management, and in particular emergency management, must be based on the availability of reliable data and on time information.

The object of this research is to propose and evaluate the application of UAS for NaTech accident emergency management and consequences evaluation (damage assessment). While the use of UAV for visual inspection of industrial plants is a diffuse approach, there is still a need for research on the application of this instruments in managing ~~events~~accidents developing in in complex, confined and semiconfined industrial environments.

The proposal implies the use of UAS (Unmanned Aerial Systems), equipped with opportune sensors, to fly. The use of these means allows to drastically reduce the risk ascribable to the use of human operators during sampling, monitoring and managing emergency events in progress. This approach provides reliable on time information on the unfolding event, avoiding human losses or injuries as far as possible.

## 2. NaTech Risk

The industrial risk, from a risk classification point of view, can be considered as a part of the wide category of man-made hazards. The man-made hazards, with some variations depending on different classifications, include: technological hazards, nuclear risk, transport risk and other anthropic activities such as business, infrastructure and technological networks management, that can be a source of danger to humans and the environment; in the man-made hazards perspective the environmental risk is related to the probability of an event caused by unexpected alteration of physical and chemical parameters in the environment (water, air and/or soil), that have


Fig. 1. NaTech accident: Tupras refinery – Izmit (Turkey) earthquake (M 7.4)

immediate, short-term or long-term effects on the health of the resident population and workers. Another definition, used in technical papers, highlights the difference between "human-made disaster" that are caused directly by human activities and "human-induced disaster", natural disaster that are accelerated/aggravated by human influence. In this heterogeneous framework of hazards, risks and events, some significant industrial accidents are known to be caused or triggered by natural disasters.

In the international literature, this type of accident is defined as NaTech or "Natural-Technological" event. One of the NaTech definitions recite as follows: "Technological accidents, like fires, explosions and toxic releases that may occur in industrial complexes and along the distribution network as a result of natural disasters of natural matrix".

## 3. NaTech Risk Management and Emergency Management

Risk management is a complex activity that requires a multidisciplinary approach. The NaTech Risk Management can be divided in various phases: prevention and preparedness (before the catastrophe strikes); response and mitigation (during the event); consequences evaluation and damage assessment (as soon as possible after the event); recovery and reconstruction (that occur after the disaster).

The prevention phase consists of all actions needed to reduce the impact of future disasters. It can be divided in structural (technical and structural solutions) and non-structural measures such as land use planning, legislation measure and emergency planning. Preparedness phase comprises the actions taken to reduce the impacts when the disaster is forecast (if possible) or imminent.

Response and mitigation pertain to actions taken during and immediately after the disaster, with the main aim to save and safeguard human lives and environmental damage.

The term recovery refers to the process of restoring services and repairing damage after the disaster has struck that obviously follows the consequences evaluation and damage assessment phase.

The emergency management requires that the local conditions and geographic characteristic of the place are properly considered, especially in term of hazardousness. Moreover, the crisis events are often characterized by rapid evolutionary dynamics, with scenarios that can often change significantly in a very short time. Therefore, better emergency management necessarily passes through the quality and quantity of observations and information, as well as the speed at which the information can be transferred and made clear and usable by decision makers.

One of the main problems of NaTech accidents is the simultaneous occurrence of a natural disaster and a technological accident, both of which require simultaneous response efforts in a situation in which lifelines and mitigation systems needed for disaster response are likely to be unavailable, as they may have been downed by the natural disaster. In addition, hazardous-materials releases may be triggered from single or multiple sources in one installation or at the same time from several hazardous installations in the natural disaster's impact area, requiring emergency-management resources occupied with responding to the natural disaster to be diverted.

## 4. Methodology

The possibility of remotely monitoring a major event with multiple spectrum analyses demonstrates the potential of aerial systems. The instruments on board also allow the point viewed to be georeferenced with decimal precision to show the major incident moment by moment.

The continual view, for example, of a fire with a thermal camera enables its movement over time to be analysed. Thus, the possible future development of the fire can be predicted and contained. A similar control can be developed during incidents involving plants, to predict the possible domino effects that may occur inter- and intraplant.

The identification of the hottest areas in the equipment, which may be involved in a fire, enable preventive manoeuvres to be used, such as cooling mechanisms of the area involved, where present.

The range of sensors that can be installed on board the craft also includes gas detectors. This enables the concentration of that specific gas to be identified in a point in space which, thanks to the GPS on board, is georeferenced. A series of samples of the concentration data enables the space and/or cloud to be evaluated over time. The data obtained in the event of a continual release can be used to obtain a map of the cloud and to identify the area of release, by using possible specific algorithms. In the event of an instantaneous release, on the other hand, it enables us to identify the direction of the trend of the maximum peak and its spread over time.

## 5. Monitoring with UAS

The proposal uses UAS (Unmanned Aerial Systems), equipped with opportune sensors, to fly in the area of the plants and to give the possibility of managing major incidents and identifying the areas of release. The continual communication of the data collected and its reprocessing at the control station on the ground enables specific, targeted actions to be taken to reduce or even to cancel undesired secondary effects (Giovani et al. 2017).

The use of these means allows the risk ascribable to the use of human operators to be eliminated both during sampling to highlight anomalies and to manage emergency events in progress. Even

though the operators hold portable alarms, their lack of knowledge of the substance could drastically increase the possibility of causing injuries to the workers.
The main feature is the possibility of regularly monitoring the areas of interest, which are at greatest risk of coming into contact with the substances being analyzed. This use enables events (releases) to be identified, which may not be identified by the normal monitoring systems and, above all, it enables rapid interventions before the spread of the substances causes greater, unpredictable damage. The capacity of the craft to fly inside and outside the buildings enables the extent of the release to be analyzed in detail.
The delay in identifying the event can cause the toxic agent to spread and increase the area of damage.

Fig. 2. Mini drones equipped with protective cage

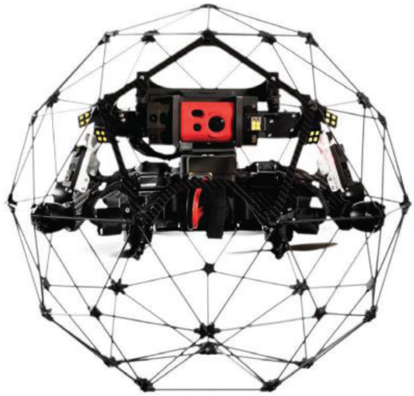

Fig. 3. Collision-resilient drone

## 6. Emergency management approach

The emergency management should follow a structured approach:
In the immediate aftermath of the NaTech accident a “swarm” of expendable programmable mini drones equipped with HD cameras should access the area of the major accident in order to provide a first real-time visual evaluation of the situation This small drone should be equipped with plastic protective cages to avoid collisions.
Following the first evaluation two different kinds of drone should intervene:
In the indoor, confined and semiconfined areas the drone should be collision-resilient for safe confined space accessibility and characterized by shockproof payload, GPS-free stabilization, distance lock, full HD live streaming of camera and thermal camera, adjustable, dustproof, oblique lighting. This drone could be eventually equipped with specific sensor in order to identify dangerous substances leakages.
In other outdoor but structurally complex areas the drone should be specifically dedicated to critical missions with extended flight time and equipped with obstacle sensing providing real time visible and thermal imagery of specific sites, structures and infrastructures and eventually of the entire area.

## 7. Applications

### 7.1. *NaTech emergency management*

Some main applications of UAS to the NaTech Accidents emergency management have been identified:

- search for survivors;
- detection and monitoring of explosions and fires;
- detection and monitoring of releases of toxic and/or flammable substances into the air.

The sensors required to identify people and animals in the debris are the visible and thermal cameras. The analysis of the visible spectrum helps identify the possible presence of movement by living creatures with direct vision and subsequent reprocessing of the data. The ability to photographically reconstruct can be used to show the damaged area in three. The use of the thermal camera, on the other hand, enables possible thermal anomalies to be identified that are people trapped under the rubble. The method designed envisages the flight of the drone with a recording in both the visible and thermal spectrum, plus the video transmission of the images taken in order to conduct an initial, rapid, on-the-spot inspection. It produces GPS coordinates as output to allow a localized investigation of the area. Georeferencing is possible thanks to the knowledge of the geographical coordinates of the drone and to the use of algorithms that work on the pixels of the images. Furthermore, the software reprocesses the radiometric video from the thermal camera, to highlight and georeference the sections with thermal variations. By applying the software and hardware, the area can be safely probed and analyzed to identify the possible location of any missing persons.
For that concerns detection and monitoring of explosions and fires UAS payload will consist of a thermal camera side by side with a visible camera, to give a view of the temperatures in the areas adjacent to the fire (essential for the identification of possible domino effects) and give a visual shot side by side of the same area. The data measured is recorded and sent to the operator, who analyses in real time the data monitored by the system. The software to be coupled with this hardware enables a slightly rough identification of the development as the event unfolds, to enable a future targeted intervention. Flight is centered on the area of interest in order to photograph the area involved in the fire as close as possible. The visible image immediately enables the equipment involved by the event to be monitored, together with the equipment which may be involved in a domino effect. Thanks to the view from the thermal camera, a study of the surface temperature of the equipment involved in the fire and the knowledge of the construction material enables the time that will elapse to be calculated before the structural collapse of the equipment. The management software in this case identifies the georeferenced conformation of the flames which, when superimposed on a map of the system, enables the adjacent equipment at risk to be identified. Vision with a thermal camera allows the temperature of the equipment hotspots to be identified and, thanks to structural algorithms inside the software, to determine the time it will take to collapse.
Finally for that concern the release of toxic/flammable substances into the air the UAS will allow to get close to the points of release inside the plants. Sensors on board: vision camera, thermal camera and gas detectors or electronic noses, will enable the substances and concentration present in that space to be identified. In the majority of cases, the concentration of the cloud is such that it does not allow the gas to be seen (unless the gas is coloured), making visual identification difficult. During flight, the data recorded by the thermal camera the vision camera and the detectors will be transmitted to the GCS screen to allow a rapid identification by the operator. The management software works side by side with systems simulating the dispersion (e.g.: ALOHA) with preset parameters inside to provide the rough structure of the cloud, together with some basic information for assessment. This will allow the monitoring of cloud and substances and the identification of possible spread in the space and type of release. The cloud could be identified from a distance thanks to the thermal camera. This is because the substances commonly sought interact with the spectral area of the infrared detected by the sensor of the thermal camera.
Outside the buildings the clouds of gas are strongly influenced not only by weather conditions, such as wind and the Pasquill stability class, but also by the structural conformations in the adjacent area, which may deviate or modify cloud dispersion. Flight has to be continually changed, depending on the images provided by the thermal camera to allow an opportune collection of georeferenced data. The ability of the craft to “follow” the cloud enables the type of release to be identified: continual or

instantaneous. An instantaneous release produces an isolated puff cloud, whereas a continual release produces a plume cloud, from which it is possible to identify the continuity with the release point. The software will allow the release point of the cloud to be roughly identified, together with its possible development over time, thanks to the analysis of the consultations present, of the models of release provided by the auxiliary software, of its movement over a short time and the shape of the cloud. The system output is the accurate positioning of the isopleths, constant concentration curves, provided by the software of the models (at possibly different intervals), which are automatically uploaded to georeferenced platforms (GIS – Geographic Information System). The use of this method enables the spatial and temporal development of the cloud to be promptly identified, as well as the point of release in the section of the system. Thus, targeted interventions can be promptly organized to limit the damage, such as the elimination of the leakage and the preparation of plans to protect the population and surrounding environment. Furthermore, the knowledge of the area which may be involved in the cloud facilitates the identification of the area to be cleared, thus reducing the polluted.

### 7.2. *NaTech emergency management*

The same UAS or a fixed wing UAS can be used for consequences evaluation and damage assessment.

The quality of the water is one of the principal environmental factors that determine human health. The identification of the release of contaminants or toxic substances into water enables the spread of the pollutant to be avoided and plans to be drawn up to limit the possible harmful development for land or water organisms and for vegetation. The use of the UAS with its specific sensors enables superficial collections and possible dissolved pollutants to be monitored via the monitoring of interactions between the toxic substance and the vegetation.

The reflected bands that can be analyzed are:

- blue (B): electromagnetic band within the visible spectrum, with maximum peak around one wavelength equal to 470 nm. It is used for atmospheric shots and for deep sea shots;
- green (G): electromagnetic band in the visible spectrum, with maximum peak around one wavelength equal to 560 nm. It is used for shots of vegetation and aquatic environments at a medium depth;
- red (R): band of electromagnetic radiation within the visible spectrum, with maximum peak at a wavelength of 600 nm. It is used to photograph man-made objects, shallow water and some types of vegetation;
- red-edge (RE): band of electromagnetic radiation placed spanning across the visible and infrared spectrum. The maximum peak is placed at 700 nm with a 50% reduction in intensity at the extremes of the interval between 680 and 730 nm;
- near InfraRed (NR): there are two electromagnetic bands that enable the internal area of the NIR to be covered: ¬ the nearest to the visible spectrum has a wavelength that falls within the interval between 700 and 830 nm, ¬ the furthest band has a wavelength with the interval extremes between 830 and 1000 nm, ¬ the latter are dedicated to the remote monitoring of natural environments.

A multispectral sensor is required. The algebraic combination of the intensity of these bands enables specific indices of identification to be created for anomalous substances compared to the water and the stress level of the vegetation to be identified (e.g. NDVI – Normalized Difference Vegetation Index) around the aquatic source. The drone needed for the operation has to protect the structure from sea salt, which can be sprayed when the craft flies at excessively low levels. The flight of the UAS varies according to the type of water under examination: - in the case of a river: the craft leaves the mouth and flies back upstream to the source, so as to identify the furthest point from the release; - in the case of a lake: flight is circular to give a global view of the stretch of water; - in the case of an analysis of the coastline: the flight runs parallel in both directions to identify the areas of land nearest to a possible contact with the substance; - in the case of open sea: flight is circular compared to the departure point and can be calibrated according to what is identified during the actual flight. This enables the complexity of the software to manage the activity to be understood to provide a considerably flexible use. The sensors on board continually provide data that is collected to allow the operator to make an initial, visual, screen check. The software to reprocess the data allows the anomalous substances to be easily identified. It is used to identify even extensive anomalies and to prepare a prompt intervention by the competent authorities to limit the dispersion of the toxic substances and limit the relative damage.

On the other hand it is difficult to inspect underground pipelines, as any loss is not directly visible. The leak of hydrocarbons or even toxic/harmful substances can lead to plausible damage of the surrounding targets, such as people and the environment. Thanks to opportune sensors, drones enable the identification not only of surface pools and saturated ground, but also of infiltrations into the subsoil. Analysis requires the knowledge of multiple data in the visible and in the infrared spectrum. The study of reflected radiation in specific bands, similar to those mentioned in the previous chapter, enables us to determine the variations in the superficial continuity of the soil, thus allowing the identification of pools and saturated ground. The reflectance of hydrocarbons differs in particular in the NIR band (Near InfraRed), which allows them to be detected. The identification of anomalies in the subsoil is possible thanks to the measurement of the ground surface temperature. The data extracted from the analysis of the bands also enables the health of the plants to be established, as this is a possible first alarm of underground losses, since the substance harms the plant. The necessary instruments on board, therefore, consist of three sensors: - camera; - multispectral camera; - thermal camera. The latter identifies the surface temperature of the objects under analysis by interacting with the radiation in the IR region (10÷12 μm) emitted by the object. The release of hot substances or a temperature that is higher than that of the ground are thus easily identified. By exploiting the thermal properties of the different substances and the thermal inertias that may be in play, it is possible to also identify underground releases of cold fluids. The data obtained by the visible cameras are transmitted continually on to two separate screens at the operator’s ground control station (GCS) to allow an easy, rough check. In the presence of any anomaly, postproduction software reprocesses the data from the multispectral and thermal cameras, in order to provide georeferenced information of the position of the loss and the images regarding the area. The outputs are designed to easily identify the possible loss and for a specialized operator to check the real danger of the event. This method enables losses to be identified rapidly even for areas extending for hundreds of kilometers. The need to identify rapidly is linked to the need to limit pollution of the surrounding soil which, if located near a water table below, could lead to a greater diffusion of the polluted water and to a greater number of potential targets.

## 8. Conclusions

The solution proposed will enable a large number of emergency situations to be covered, in which there is considerable risk for human health and for the surrounding environment. The graphic interface enables data to be interpreted immediately. Immediate intervention on the scene of an incident requires basic effective methods. Information about the event could be gathered in real time and enables the problem of time to be solved to allow services to arrive as soon as possible at the scene of the incident. These systems allow us to control vast areas without the need for direct human intervention and to reduce as far as possible the area of damage in an accidental event. This is the result of a craft with the ability to fly in the area of accident and, at the same time, to provide a very detailed view in certain precise bands of spectral analysis of the situation facing the UAS.

The application of Unmanned Aerial Vehicles (UAV) is an effective tool for response and disaster management.

Furthermore, this system avoids using human life as far as possible, since this cannot be replaced in the event of an accident, unlike the UAS. Therefore, this method reduces the risk for the operators to a minimum.

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