EU CURSOR Drone Fleet: Fast and Cost-Effective Rescue of Victims Buried under Rubble

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Abstract - *Member States in the European Union have faced devastating earthquakes, challenging First Responders in their Search and Rescue (SaR) capacity. In response to these challenges a European-Japanese consortium initiated the project CURSOR (www.cursor-project.eu) and received support within the EU Horizon 2020 Programme (EU Grant Agreement no. 832790) and from the Japan Science and Technology Agency. One primary objective is to develop an innovative CURSOR SaR Kit that will be mobile, fast to deploy and easy to operate. In addition, CURSOR focuses on the reduction of time needed for deployment of SaR personnel and equipment, for situational assessment during urban SaR operations and for onsite disaster response. An important component of the SaR Kit is the CURSOR Drone Fleet, consisting of: (1) Tethered drone with HD video camera, flood lights, megaphone and WiFi access point, serving as 24/7 „Eye in the Sky" at the disaster zone ; (2) Five drones in swarm formation, providing a HD video overview and a 3D model of the disaster zone; (3) Ground penetrating radar mounted on a drone, identifying buried victims; (4) Heavy-lifting drone, carrying a container filled with ground-based robots, equipped with sensors and flying to locations with high probability of finding survivors. Each drone underwent ruggedization, as well as tests under laboratory conditions and in the field.*

Key Words: Earthquake, Buried victims, Search and rescue operation, Drones, Sensors, Speed, Cost effectiveness.

1. INTRODUCTION

Earthquakes are widespread in the Europe and seismic risk in Europe is substantial in some areas. The most destructive events occurred in the Mediterranean countries, particularly Greece, Italy and Turkey. These countries are in the collision zone between the Eurasian and African crustal plates. Also, Albania and Romania have experienced major earthquakes [1]. In the period 1960 to 2020, 122 earthquakes caused more than 10100 recorded fatalities, over 38000 injured, more than 616000 homeless and overall losses of about EUR 56 Billion[2].

Tragically, an earthquake represents a low-probability, high-risk scenario, which is difficult to anticipate. Therefore, responding to such natural disasters has proven to be a challenge to the worldwide First Responder (FR) community.

Remotely Piloted Aircraft Systems (RPAS; drones) have reached a significant level of maturity in the military domain. Over the past few years, the market for civilian drones, flying in non-segregated airspace, has started to become more prominent among FRs as a mean to increase situational awareness. Information acquisition during crisis situations can be done using a large variety of drone platforms, ranging from micro-drones to large drones. RPAS manufacturers have been keen on presenting the added value of their own products but in doing so usually validate the fact that no single platform approach offers the full spectrum of flexibility each stakeholder would require.

Drone technology is progressing fast internationally for two main reasons:

- *Cost:* One of the main reasons is lower operational costs of drones as compared to helicopters. For example, a police helicopter costs about EUR 350/hour to fly [3]; operational costs of drones are less than EUR 1/hour. Besides the cost factor associated with operations, drone industry and research institutions have developed drones with a low initial purchasing cost, ranging from a few hundred to some tens of thousands of EUR, depending on the application and performance (flight time, payload, degree of autonomous operations).
- *Diversity of drone models and applications*: A large number of different drone models has been developed in recent years. The wide range of drone models available internationally necessitated to categorize them into two main classes, based on their take-off weight (TOW) [4]:
  - *Class 1 (TOW <150 kg)*: Micro drones (<2 kg), Mini drones (2-20 kg), Small drones (<150 kg);
  - *Class 2 (TOW 150 – 400 kg).*

Within the framework of the CURSOR project, the potential use of Commercial-off-the-shelf (COTS) equipment in the newly designed *CURSOR Drone Fleet* (DF) was analysed, encompassing altogether 38 drone and sensor-related systems. The analysis accounted for typical real-world conditions encountered by Search and Rescue (SaR) teams in times of crisis, handling of the equipment, maintenance and cost for different drone categories. This paper describes the characteristics, strength and limitation of the DF.

2. CURSOR DRONE FLEET

As every crisis is different, it is impossible to provide one solution which fits all needs. Therefore, *one size drone fits all* is not a viable option for managing the aftermath of an earthquake with the support of drones. In order to tackle the challenges brought on by an earthquake affecting a large urban area, it was decided to use a combination of: (a) one common drone airframe (*GAIA 160*) with special sensors for heavy-lifting tasks (ground penetrating radar (GPR); ground-based miniaturized robots to be released on scene (SMURFs; details at *www.cursor-project.eu*); (b) one special airframe (*DJI Mavic Pro*) for a swarm of fast, small drones providing advanced situational awareness (initial HD video and subsequently 3D model of disaster area). DF enables crisis mangers to identify risks and emergencies due to damaged structures (e.g., zooming into sections of buildings), to detect survivors under rubble (e.g., radargram), and to provide communication services (e.g., public alerting via megaphone; WiFi access point). The different types of data provided by the DF are integrated into the Common Operational Picture (COP) for the crisis managers.

This increases the effectiveness of rapid and coordinated response in SaR1 operations, ultimately resulting in improvements in victim survivability through enhanced capabilities in the detection of persons. In addition, medical response to victims will be improved through remote detection of the victim status (movement, breathing), and provision of psychological support (communication with buried victim through megaphone).

The DF consists of one Mothership Drone (MD), one GPR Drone (GPRD), one Transport Drone (TD) and five drones used as Modelling Swarm Drones (MSD).

2.1 Mothership Drone (MD)

Figure 1 shows the *CURSOR Mothership Drone (MD)*, based on the GAIA 160 airframe. The MD meets the following specifications:

- Stationary, tethered electric power system (Base Station) and 100 m long special cable connecting a mobile electric power system on the ground to the drone. The special cable incorporates also an optical cable for data transmission from the MD to the Base Station on the ground;
- GAIA 160 Heavy-lift hexacopter with six motors/carbon fibre propellers;
- Dual landing gear with multilayered foam for reduction of the kinetic energy impact upon landing;
- DJI A3 PRO flight controller;

Fig -1: Tethered Mothership Drone (MD) with ground-base (black) and two mobile power supply units (red)

- LiPo batteries (2x 12S 16 Ah; 12S 32 Ah);
- Encrypted HD video transmission;
- EFT V3 High current power distribution board;
- 30x Optical zoom-camera;
- 2x Floodlight 100W LED lamps;
- 1x Megaphone system 125db (max);
- Parachute for emergency landing of drone;
- Tethered voltage converter;
- Glass fibre signal converter;
- WiFi access point;
- Special heavy-duty drone-system transport case.

2.2 Ground Penetrating Radar Drone (GPRD)

Figure 2 shows the drone GAIA160 in the configuration as *CURSOR GPRD* with the ground penetrating radar sensor (GPR) hanging from a cable on a remotely controlled winch. The GPR detects survivors buried under several meters of debris and differentiates between slight movement, strong movement and breathing. The actual penetration depth depends inter alia on the type of material; the system does not work in a debris pile containing iron-reinforced concrete due to undefined radar reflections. The GPRD meets the following specifications:

- GAIA 160-Heavy-lift hexacopter drone/carbon fibre propellers and associated features described for the MD;
- Remotely controlled electric winch for lowering GPR sensor onto measurement site (e.g., debris cone);
- Mobile GPR unit in ruggedized transport container;

Fig -2: Ground Penetrating Radar Drone (GPRD) transporting radar sensor

- Dual landing gear with multi-layered foam-impact reducer;
- DJI A3 PRO flight controller;
- Lipo batteries 12S 32 Ah;
- Encrypted HD video transmission;
- Stabilized X5 15mm F/1.7, 4K HD camera;
- EFT V3 High current power distribution board;
- 2x Floodlight 100W LED lamps;
- Special heavy-duty drone-system transport case.

2.3 Transport Drone (TD)

Figure 3 below shows the drone GAIA160 in the configuration as TD with a prototype transport container. The TD is equipped with HD video camera, thermal camera, as well as floodlights and a megaphone. HD video transmission is encrypted.

Fig -3: Transport Drone (TD) transporting SMURFs in special container with remotely controlled release

The TD is able to carry a special container for unloading SMURFs (with special sensors onbord; details at www.cursor-project.eu) at selected sites to identify victims buried under rubble. This drone meets the following specifications:

- GAIA160-Heavy Lift hexacopter drone/carbon fibre propellers and associated features described for the MD;
- Special container for unloading SMURF units at selected sites under remote, wireless control;
- Dual Landing Gear with multilayered foam-impact reducer;
- DJI A3 PRO flight controller;
- Matrice 600 Pro mounting plate for Zenmuse XT2;
- 2x Floodlight 100W LED lamps;
- Encrypted HD video transmission;
- EFT V3 High current power distribution board;
- High resolution radiometric Thermal & HD RGB camera;
- RTK GPS expansion.

2.4 Modelling Swarm Drone (MSD)

Figure 4 shows the MSD in operation. This system is comprised of altogether five DJI Mavic Pro (MP) drones operating as a swarm. The MSD meets the specifications listed below.

Aircraft Specifications:

- Diagonal size (propellers excluded): 335 mm
- Weight (battery, propellers, gimbal cover included):743 g
- Maximum speed: 65 km/h
- Maximum flight time (no wind): 27 min
- Maximum service ceiling above Sea Level: 5 000 m
- Operating temperature: 0° C to 40°C
- Satellite positioning: GLONASS (Russia) and GPS (USA)
- Hovering accuracy: vertical - +/- 0.1 m; horiz. - +/- 0.3 m

Vision System:

System direction: Forward and downward

Precision measurement range: 0.7 m to 15 m;

Detectable range: 15 m to 30 m

Operating Environment: Surface with clear pattern and adequate lighting (lux > 15).

Fig - 4: Five drones used for modelling swarm (MSD), with 6th drone filming swarm in operation

Camera Specifications:

DJI Mavic Pro (MP) uses a large sensor (SONY Exmor 1″; sensor size: 116mm vs. 29mm). Since more light impacts on the sensor, this results in a higher image quality. Focus of the MP28 mm lens is adjustable and automatic. A headset displays an 85° view from the drone with two 1920 x 1080 display screens, up to 1080p image transmission and low latency wireless connection.

Sense & Avoid Technology:

SOTA consumer drones deploy three types of "sense and avoid" technology:

1. Sonar – Sound waves bouncing off a nearby surface. Sonar can detect large objects (like the ground) at a distance up to 6 m.

2. Infrared – Infrared sensors limited to toy-drone mode (various technical shortcomings).

3. Camera - Downward facing low-resolution camera, capable of pattern recognition (e.g., floor tiles).

MP uses high resolution cameras on the drone body. These cameras feed information into a specialized processor, which provides computer vision. The cameras, along with 2 ultrasonic sonar sensors, assist with avoidance- of-obstacles during the flight and ground sensing, as well as increase drone stability.

Flight Modes:

Three intelligent flight modes are incorporated in the MP drone system:

1. Obstacle Avoidance: In combination with the front sensors the drone can determine how to clear objects, such as vehicles, etc.

2. Active Track: Forward cameras recognize and track objects, such as persons, etc.; it allows MP to position itself around the subject in various ways.

3. TapFly: Allowing for "point and fly" on the screen control, this mode includes avoidance and/or recognition of objects.

To create a 3D model from aerial photogrammetry, the camera is mounted on the drone and can be moved vertically and horizontally under remote control. Multiple overlapping photos of the ground or object to be modelled are taken as the drone flies along an autonomously pre-programmed flight path, called a *Waypoint (WP) Mission*. To overlap photos of an object or land by 80% to 90% would be impossible to complete accurately by pilot navigation. Therefore, the MSD was designed to incorporate computer-aided WP navigation technology, using the *Universal Ground Control Station* (UgCS) software. The software architecture is built upon a client-server system. It is possible to separate the ground control station – providing the broadcast uplink to the drone - and the mission control carrying out mission planning and flight operation. Figures 5 shows an example for a UgCS-based MSD photogrammetry mission.

Fig -5: Example of UgCS-programmed MSD mission

2.5 CURSOR Drone Control- and Energy Supply Systems

All four drone systems (Mothership Drone, Ground Penetrating Radar Drone, Transport Drone, Modelling Swarm Drone) use the same software suite and hardware for drone-control and drone-energy supply as described below.

Drone Control System

DF can be controlled manually via remote control (e.g., MD, GPRD, TD) or by pre-programming UgCS, the preferred control mode for MSD. Drone control in the DF applies the soft- and hardware listed below:

Software: UgCS for mission planning; e.Calc; UgCS for DJI app; DJI Assistant 2; Android (latest version), Pix4D.

Hardware: Notebook for UGCS; tablet for UGCS app – HDMI out; HDDs /SSDs ; WLAN Hotspot.

Drone Energy Supply System

The DF is electrically powered, using LiPo batteries installed on-board. Batteries are charged with special chargers via an *Intelligent Battery Charging* (IBC) hub. The IBC system charges batteries in sequence, according to their power levels, from high to low. It offers the following modus operandi: Balance Charge, Storage und Charge Mode.

A special feature is the electric energy supply of the MD. MD is supplied with a tethered electric energy system (TEES), which provides an (almost) unlimited power source. With TEES, the MD can fly as long as required without any concerns about the need to land in order to change batteries, except for refuelling petrol in the 2 mobile power supply units (see below). MD is physically connected to a mobile power station on the ground, using a specialized hardware tether cable. This high-tech tether cable contains lightweight, thin conductors, which reduce the wind drag and enabling the drone to reach an altitude of around 100 m. ISCC has adapted the tether with an additional optical fibre-cable for the transmission of data from the MD to the Base Station on the ground. Live aerial monitoring data can be wirelessly shared to monitors through the relay station.

TEES, in line with two mobile power generators, converts AC electricity into higher-voltage DC. The drone itself also has a DC-DC converter on board to supply lower-voltage power to the camera system and other components. The tethered MD is easy to retract, using an electronically controlled and air-cooled winch-system.

The tethered MD has a reduced spatial area where it can fly. Because of the flying restrictions due to the tether, the pilot can focus on other mission-related tasks. Also, MD does not require GPS navigation, which is a significant contributor to reducing any technical errors that can lead to drones crashing. Thereby, tethered drones dramatically reduce technical and human error-induced crashes in flight. Whilst free-flying drones have typically an average flight time of about 15 to 30 minutes on a single, full battery charge, tethered MD can stay in the air until a problem occurs with the grounded mobile power source, or such as a motor- or propeller failing.

Another benefit of tethered drones is providing more explicit pictures, e.g., by zooming in on details in a 360° surround photo. Furthermore, using a tether means secure communications, which cannot be jammed and is immune to interference. It is important to ensure that a fully integrated tethered system is installed. Such a system includes: Ground station, remotely controlled winch and cable tension, tethers, data transmission, communication links, and a drone plus sensors that are all designed to work together.

TEES meets the following specifications:

- 100 m long tether cable (electric and optical).
- Autotrack cable tensioning capability
- Provision of 3500 W electric power to the MD
- Cable Weight: 1.6kg
- Output Voltage: 12S
- Output Power: 3500W
- Voltage Input: 230V AC 50Hz
- Onboard Unit Voltage output: 50V
- Tensile Strength: 50kg
- Climbing/landing Speed: 1.5m/s.

3. ON-BORD SYSTEMS

3.1 Cameras

All drones in the DF are equipped with optical cameras; GPRD and TD also have additional thermal cameras. Camera characteristics are listed below.

OPTICAL CAMERA *ZENMUSE Z30*

Zenmuse Z30 offers image data capture with an optical zoom up to 30x and digital up to 6x. Thereby, it is possible to capture the information required from a greater range, making image data collection significantly faster and eliminating the risk of harm to both personnel and equipment by flying drones too close to the target (e.g., collapsed building).

Effective Pixels: 2.13 M

F-value: F1.6 (Wide) - F4.7 (Tele)

Electronic Shutter Speed: 1/30 – 1/6000 s

Video Captions. Defog and TapZoom : Supported

Focus Movement Time ∞ to near: 1.1 sec

Gimbal Angular Vibration Range: ±0.01°

Gimbal Controllable Range: Pitch : +40° to -90°, Yaw: ±320°

THERMAL CAMERA *ZENMUSE XT2*

Pairing the FLIR Tau 2 thermal sensor and 4K visual camera with high-end stabilization and machine intelligence technology, the Zenmuse XT2 transforms aerial data into thermal images.

Thermal Imager: Uncooled VOx microbolometer

Digital Zoom: 640×512: 1x, 2x, 4x, 8x; 336×256: 1x, 2x, 4x

Pixel Pitch: 17 µm

Spectral Band: 7.5-13.5 µm

Full Frame Rates: 30 Hz

Sensitivity (NEdT): <50 mk @ f/1.0

3.2 Drone Lights

The lights mounted on the drone airframe consist of 2x 100W LED lamp units with heatsink and fan (Figure 6). The butterfly-shaped design of the heatsink creates a larger heat dissipation area, which improves the overall heat dissipation performance, avoiding LED overheating. The lamp chip is covered by a 120° lens, focusing the light output. The mounting of this energy-saving lamp is optimised for adjustable use under remote control, enabling drone-based illumination of the operational site at night. Lamp characteristics are summarized below.

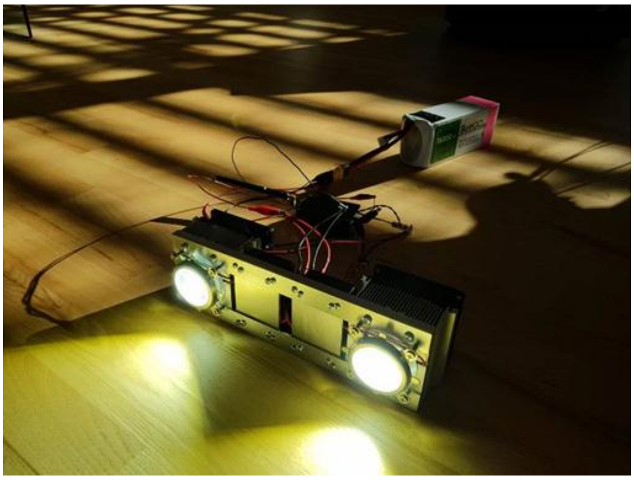

Fig - 6: LED flood lamps with fan-assisted heatsink, mounted on drones MD, GPRD and TD

Fan voltage: 12V DC

Fan dimension: 80x80x28mm

Aluminium heatsink dimension: 82x80x40mm

LED bead input voltage: 30-35V DC

Power: 30W/50W/100W

Light colour: Cool white

Life Span: 50000 Hours

Glass lens diameter: 44mm

Height: 11.2mm

Angle: 120 or 60 degrees

3.3 Drone Megaphone

The on-bord drone megaphone (DM) has been specially designed for installation on drone airframes (Figure 7).

Fig - 7: Remotely controlled megaphone on-bord of MD

DM features a lightweight, small size structure with an aerodynamic design. This enables the drone to fly with low atmospheric resistance in the air, saving energy and thereby prolonging operational flight time. The megaphone supports real-time broadcasting. The sound strength is about 125dB (max.); at about 100m it drops to about 65-78dB. The audio transmission distance is about 5km. The application focuses on calling attention to a sudden, unplanned event during an SaR operation (e.g., imminent threat of a building collapse).

3.4 Payload Container for Transport Drone (TD)

The Transport Drone (TD) is optimized to carry a container for delivering to and unloading ground-based robots (SMURFs; details at https://www.cursor-project.eu/) at the site selected for SaR operations. The transport mechanism is a mechanical interface system between a load of about 10 SMURFs and the TD. Currently, the prototype container foresees a sliding rail dispenser (Figure 8). In the container several SMURFs are suspended from an inclined slotted rail with an integrated T-hook. The sensor payload slides to the release mechanism at the lower end on its own by gravity.

Fig - 8: Sliding rail-type dispenser on payload container for TD

The SMURFs are unloaded one by one by dropping them under visual control (video camera) from less than 1 m height at a site selected by the crisis management.

4. Ruggedization and Safety

Ruggedization- and safety tests used partial or full simulations of physical test environments in a climate chamber, respectively during field tests in an Alpine environment. The latter used a gravel pile on top of a concrete tube, simulating a buried victim with a remotely controlled, motorized dummy positioned inside the tube.

The climate chamber has the following characteristics:

- Floor size: 4 x 6 m^2
- Room height: 2.5 m
- Controls: Electronically regulated ambient air temperature and relative humidity.

The Alpine test environment has the following characteristics:

- Location: Mountain valley, Salzburg (Austria)
- Altitude: 625 m above Sea-Level
- Environment: Mountains (up to 1783 m above Sea-Level).

The man-made gravel pile on top of the concrete tube has the following characteristics:

- Pile material: Gravel (gravel diameter: <70 mm)
- Pile base diameter: 5 m
- Pile height: 2.5 m
- Concrete tube diameter: 0.6 m.

Figure 9 shows MD during an Alpine storm test (wind gusts up to 60 km/h).

Figure 10 shows a dummy (male torso) with electrically powered simulation of breathing in a concrete tube underneath a gravel pile. Drones and TEES are protected against dust and precipitation. All drones, operational control systems and required accessories (smart phones, batteries, landing pads) are housed in custom-formed transport containers.

Testing of the CURSOR DF will continue jointly with first responders during field-tests planned for 2020/2021.

Fig -9: MD during storm test (wind speed up to 60 km/h)

In order to ensure a high standard of safety, redundancy and fail-safe technologies in the drones and their operating equipment are foreseen. This includes, for example, safety mechanisms to protect the operators and bystanders with rotor cages, redundant power supply on bord of MD, and parachutes on bord of GPRD and TD.

Fig - 10: Test dummy (with breathing simulator inside chest), positioned in concrete tube underneath 12 t of gravel, for ground penetrating radar measurement (radargram)

5. Conclusions

A comprehensive survey of commercial-off-the-shelf (COTS) available equipment was carried out, comprised of the analysis of altogether 38 drone and sensor-related systems (number of systems investigated in parenthesis): drone (17), autonomous modelling (4), swarming capability (7), ground penetrating radar (5), drone control software (1), and tethered energy systems (4).

The hardware selected in the COTS survey was subjected to laboratory- and field tests. All systems can operate within an ambient air temperature range of -10°C to +55°C and atmospheric relative humidity between 30% and 100%. It is cautioned though that this high-tech equipment is sensitive to dropping onto a hard surface from heights exceeding 30 cm. Ruggedization measures on drone landing gear reduces this risk to some limited extent. Also, ruggedized, tailor-made transport containers have been developed to reduce the risk of damage during transport.

Multiple safety features were implemented for reducing the risk to operators and bystanders during drone operations.

The components of the DF provide FRs with the following capabilities within 60 min after arrival on scene:

a. Aerial HD photos, HD video and thermal images of the disaster area, based on an aerial survey by the GPRD (without the GPR);

b. Continuous drone-based aerial surveillance at a selected height above ground with the tethered MD, equipped with a HD zoom-camera, flood lights and megaphone. The location of the tethered MD can be changed and adapted to the needs of first responders;

c. Low resolution 3D model of the disaster area, created by MSD and dedicated workstation after approximately 40 min (high resolution model after 2 hours);

d. Ready-to-use ground-penetrating radar (GPR), mounted on GPRD, for detecting survivors under debris;

e. Transport and unloading of SMURFs in selected areas by TD.

The DF will be further optimized during the remaining project time, accounting for the feedback by first responders and results obtained during further lab- and field exercises.

Also, training of first responders on the use of this equipment is foreseen during this period.

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