The CURSOR Search and Rescue (SaR) Kit: an innovative solution for improving the efficiency of Urban SaR Operations

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ABSTRACT

CURSOR (Coordinated Use of miniaturized Robotic equipment and advanced Sensors for search and rescue OpeRations) is an ongoing European H2020 project with the main objective to enhance the efficiency and safety of Urban Search and Rescue (USaR) operations on disaster sites. CURSOR' s approach relies on the integration of multiple mature and emerging technologies offering complementary capabilities to an USaR system, so as to address several challenges and capability gaps currently encountered during first responder missions. The project's research and development are structured around an earthquake master scenario. CURSOR aspires to advance the state-of the-art in several key aspects, including reduced time for victim detection, increased victim localization accuracy, enhanced real-time worksite information management, improved situational awareness and rescue team safety.

Keywords

Urban search and rescue, victim detection, rescue robotics, sensors, situational awareness.

INTRODUCTION

In Urban Search and Rescue (USaR) operations following natural or man-made disasters, such as an earthquake or an explosion, time is of utmost importance. SaR teams and other First Responders (FRs) race against the clock in a time-critical and often hazardous environment to locate survivors within the critical "72 golden hours" timeframe. This is where CURSOR, an EU and Japan Science and Technology Agency funded project comes into play. The CURSOR project aims to deliver the design and prototype of an innovative SaR Kit, comprising several mature and emerging technologies and subsystems, with the ultimate goal of improving the efficiency of USaR operations on disaster sites.

Today, USaR FRs still rely mostly on conventional technologies presenting several limitations, such as limited sensor capabilities, heavy and difficult to move scanners, inadequate worksite data analysis, and unreliable network communications (Kedia et al, 2020, Statheropoulos et al, 2015). CURSOR addresses several current limitations and capability gaps in USaR by embracing an integrative approach which combines several complementary technologies into a single platform, so as to boost efficacy and reliability. Key innovative elements in relation to the current state of the art in USaR operations include the following:

- Situational awareness, victim detection and localization supported by integrating information from several different types of ground-based and aerial sensors. A team of multiple agents is thereby working collaboratively, having the FRs at the center of all activities.
- Small ground-based robotic devices are designed to exhibit higher mobility and autonomous function in debris than ever before.
- Innovative chemical sensing platforms offer high victim identification rates never achieved before with similar technologies.
- Drone fleet consisting of drones with different sensors, providing comprehensive assessments in shorter time and at lower cost than currently possible, while reducing the risk of bodily harm to FRs.
- Possibility to transport specialized equipment (robotic devices, ground penetrating radar) to inaccessible rubble piles.
- Resilient communication and localization solutions adapted to the post-earthquake debris environment.
- More convenient user interfaces

More specific information about the novelties introduced by the individual CURSOR Kit components is provided within the following sections. Overall, the project aspires to advance the state-of the-art in several key aspects, including reduced time for victim detection, increased victim localization accuracy, enhanced real-time worksite information management, improved situational awareness and rescue team safety.

An internal on-going collaboration between leading USaR FRs and experienced technology solution providers, engaged together in a co-design process, lies at the heart of the CURSOR approach. An external FR Board provides valuable feedback throughout the project lifetime.

The present article presents key approaches and summarizes the current state of research and development of the project.

OPERATIONAL SCENARIO

The CURSOR SaR Kit solution is designed around a realistic earthquake scenario resulting in the destruction of urban buildings and trapping of victims under the rubble. The operational scenario encompasses a Master Scenario and three Use Cases and provides a framework to employ, design and develop the technologies of the project. The Use Cases are aligned with Assessment Search and Rescue (ASR) levels 2-Wide area search, 3-Rapid SaR and 4-Full SaR (INSARAG Guidelines), the latter one being the most relevant to CURSOR.

The Master Scenario has been constructed using information and data from actual deployments and gives a pragmatic overview of the challenges FRs are facing on the disaster site, so as to reveal current capability gaps where the efforts for research activities and technology provision should focus. It includes both general information about the conditions of the considered disaster incident as well as information about the envisioned role of the CURSOR SaR Kit in the context of the distinct phases of the USaR response cycle (e.g. tasks to be performed, equipment to be used).

Based on the identified FR needs and capability gaps, related functional and non-functional requirements for the technological components of the CURSOR SaR Kit have been determined by the end-user partners of the project and served as the foundation for the definition of the technical requirements and specifications of the various technological components and the design of the system architecture.

CURSOR SAR KIT COMPONENTS AND SYSTEM DESIGN

The CURSOR SaR Kit features a combination of Commercial-Off-The-Shelf (COTS) and newly designed and developed hardware and software components. The foreseen technological solutions are grouped into two major categories: a) disaster worksite components used by the FR personnel, and b) information management components for the higher command/mission coordination personnel at the USaR Coordination Cell (UCC). Key design principles include mobility, modularity, reliability, quick deployability, ease of operation, and reliance on open standards and protocols for future sustainability.

The Kit comprises the following main components: i) Soft Miniaturized Underground Robotic Finders (SMURFs): devices equipped with a range of sensors, including an innovative chemical sensing platform, ii) Drone Fleet (DF): a fleet of four types of drones contributing different capabilities into the SaR Kit, iii) wireless geophones, iv) a resilient and secure communication solution based on multiple stationary and portable emergency gateways that provide a seamless network on all deployed components, v) a data fusion and event processing engine, and vi) two Common Operational Picture components, one residing at the UCC and the second, portable one, at the worksite, providing visualization and mission coordination capabilities. Table 1 lists the main components of the CURSOR SaR Kit, while Figure 1 provides a corresponding schematic diagram.

Table 1. CURSOR SaR Kit main components

Component	**Basic description *[Location]***
Common Operational Picture (COP)	Workstation providing the overall operational view, supporting mission coordination by higher command personnel *[UCC]*.
COP Terminal (COPTERM)	Rugged tablet controlled by the FR team leader that communicates with the COP. Retrieves all worksite information from the EXPER middleware server *[Worksite]*.
Drone Fleet (DF)	Mothership Drone (MD), Transport Drone (TD), GPR drone (GPRD), five Modeling Swarm Drones (MSD) *[Worksite]*
Emergency Gateway (EG)	The computing platform(s) controlling the CURSOR SaR Kit's networking *[Worksite/UCC]*
EXPER	Complex event processing system comprising the Expert Reasoning Engine (ERE, performing data analysis and exploitation) and the Multi-Source Data Fusion Engine (MDFE, handling information flow across CURSOR components and heterogeneous data fusion) *[Worksite]*.
Geophone kit	Array of (at least) 2 wireless geophone kits, resolution digitizer, visualization tablet *[Worksite]*.
Ground Penetrating Radar (GPR)	Sensor providing radagrams at locations of suspected survivors *[Worksite]*.
GPR Drone (GRPD)	Heavy-lifting drone with a GPR sensor as payload *[Worksite]*.
Modelling Swarm Drone (MSD)	Swarm of five pre-programmed drones for acquiring georeferenced orthophotos of the target area *[Worksite]*.
Mothership Drone (MD)	24/7 "Eye-in-the-Sky" drone, providing continuous local situational awareness *[Worksite]*.
On-site Drone Controllers (OSCTRL)	Flight controller for the MD, TD, and GPRD, flight pre-programming software for the MSD *[Worksite]*.
On-site Drone Server (OSSRV)	Server gathering data produced by drones *[Worksite]*.
On-site Drone Workstation (OSWS)	PC performing drone orthophoto-based photogrammetry for 3D modeling of the target area *[Worksite]*.
Sniffer	Gas sensor platform for differentiating between living and deceased victims. Integrated into the SMURF *[Worksite]*.
Soft Miniaturized Underground Robotic Finder (SMURF)	Ground-based robotic platform carrying a range of components supporting victim detection and localization [*Worksite]*.
SMURF Workstation (SMURF WS)	Rugged laptop for interacting with swarms of SMURFs and relaying SMURF data to the EXPER system via the EG*[Worksite]*.
Transport Drone (TD)	Heavy-lifting drone for transporting and unloading SMURFs to unreachable rubble piles *[Worksite]*.

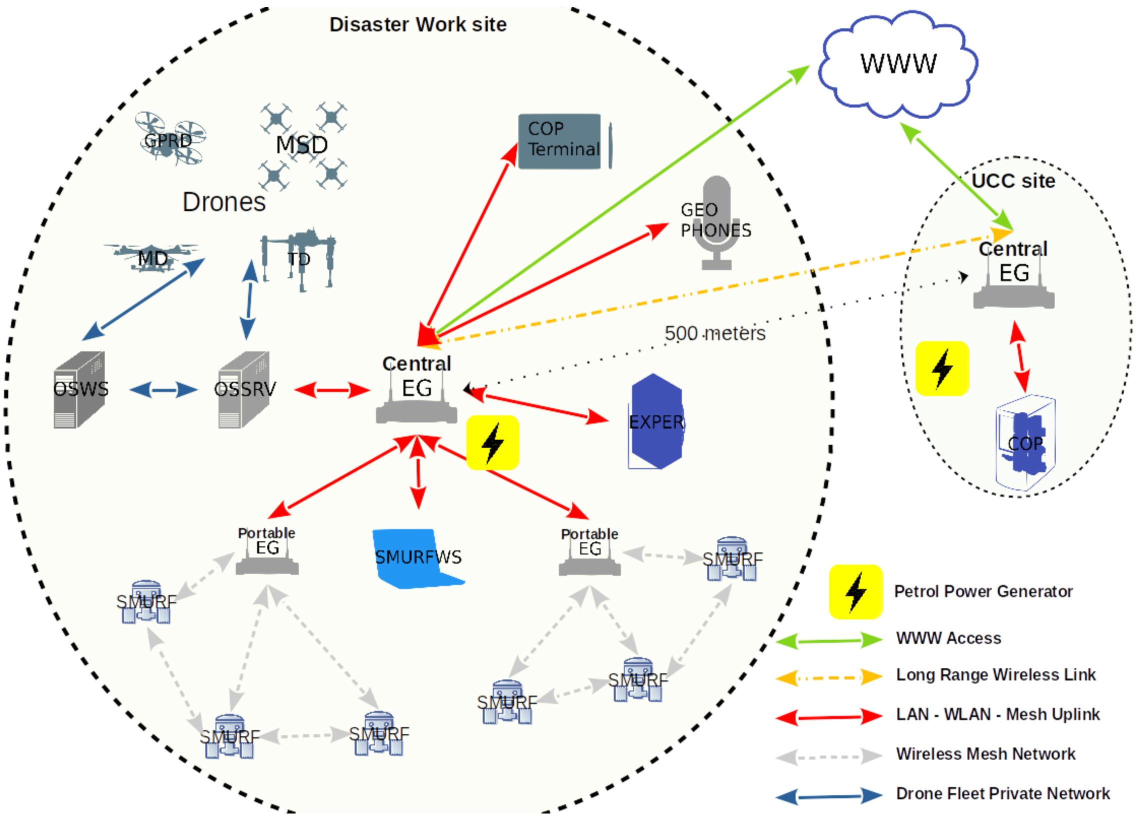


Figure 1. The CURSOR SaR Kit: 10 mile view

More specifically, a Local Area Network (LAN) is established by the stationary central EG residing at the worksite, offering networking facilities via multiple wired and wireless equipment (WLAN). The UCC site components are linked seamlessly into the worksite LAN via a long-range wireless link. The components participating in the worksite LAN/WLAN are the EXPER system, the COP Terminal, the OSSRV, the SMURF Workstation, the Geophone tablet, and a number of portable gateways; the latter bridge the Wireless Mesh Networks (WMN) set up among SMURF team members, operating at specific rubble piles, with the central EG and thereby with the rest of the LAN/WLAN. The components of the Drone Fleet are interconnected in a private drone network, with the OSSRV serving as the gateway to the EG. The central EGs act also as Internet gateways. COP is connected to the LAN/WLAN of the UCC site. All components can transparently route traffic to all other components.

CURSOR SaR Kit Components

Soft Miniaturized Underground Robotic Finder (SMURF)

The SMURF is a small ground-based robotic platform that carries subsystems such as sensors, actuators, communication, and localization modules, in order to collect crucial pieces of information about trapped victims. Its design aims to achieve higher mobility around and into debris and more autonomous functions than ever before, while offering a cost-efficient manner of detecting trapped victims. The SMURF can be deployed either manually or carried within a prototype container of the Transport Drone and unloaded onto unreachable rubble piles (Figure 2). By deploying multiple SMURFs, multiple units of advanced chemical sensors, offering high victim identification rates, are distributed in the rubble pile. The main components of the SMURF are:

- **Motherboard**: the SMURF motherboard is a custom Printed Circuit Board (PCB) prototype designed and developed to connect all the internal SMURF components.
- **Sniffer module**: an innovative miniaturized gas sensor platform, composed of two submodules: a) A novel sensor array technology combining Quartz Crystal Microbalance transducers with ligand binding

proteins (LBP) involved in olfaction in Nature. Chemical interactions of Volatile Organic Compounds (VOCs) with the LBP sensitive coatings produce a measurable shift in the resonant frequency of each transducer. The primary objective of the Sniffer module will be to differentiate living from deceased victims to help prioritize USaR operations. To our knowledge, it will be the first Sniffer device to use proteins designed by Nature to detect odorant molecules for victim search. By combining this with the COTS sensors high victim identification rates never achieved before with similar technologies are expected.

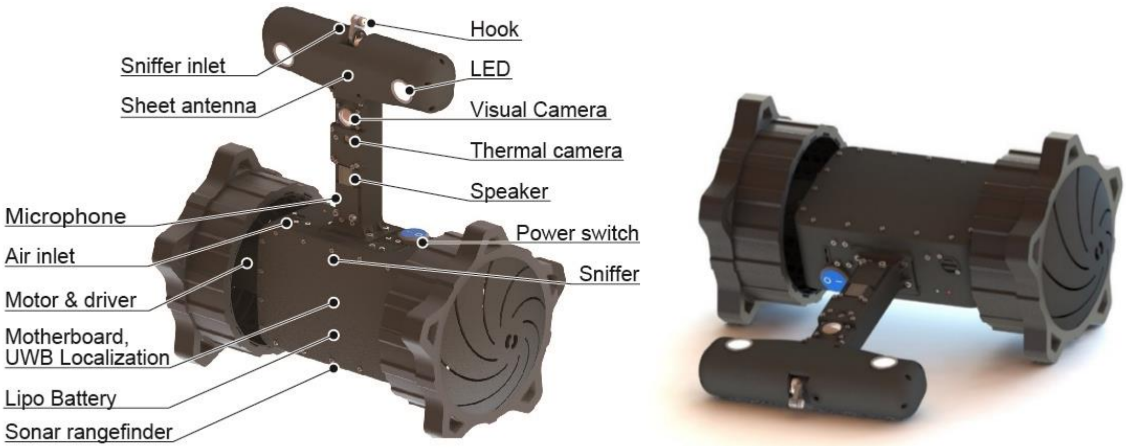
Up to now, a first Sniffer prototype was tested in the field to assess its potential for detecting the presence of human victims in closed cavities similar to those encountered after building collapses. The presence of deceased bodies was simulated using chemical makers. Both human volunteers and the chemical markers of deceased persons could be detected efficiently. Measuring VOCs and CO_2 along with environmental parameters showed promising results towards the discrimination of deceased and living victims but also allowed to free oneself for interfering events such as rain, the presence of smoke and other perturbations occurring in the vicinity of the victim.

- **SMURF Localization Module**: custom PCB solution based on Ultra-Wide Band technology, providing a SMURF with knowledge of its position, an important functionality in terms of victim localization. The localization system consists of anchor (placed around a rubble pile) and tag (within the SMURF) nodes that work together to calculate the position of the tags. The core component of the system is the radino32 module. While the module on its own is a very competent solution, it was designed mainly for line of sight scenarios. For acquiring a solution suitable for use within a debris environment, our research has been focused on: i) Increasing the localization module's transmit power and decreasing its noise figure so as to achieve as deep penetration into debris as possible, and ii) Extending the receiver's range in which the received signal strength can be reliably measured. For calculating its position, the module first needs to determine its range from known points: the time of flight of radio packets is measured and then translated into distance using the radio wave's speed. Since the transmission speed depends on the type and extent of materials encountered, measurements of the signal's attenuation are used to correct for this error and it is thus important to be able to measure the receiver's signal strength.
- **SMURF Communication Module**: Establishing wireless communication between SMURFs searching within debris and their operators is challenging due to the signal attenuation caused by various building materials. CURSOR addresses this problem by using a swarm of robots, where each robot acts as a communication node of a wireless mesh network (WMN), and robots penetrate the debris few at a time. In addition, using a portable device (portable EG) that is able to participate both in the WMN and the local WLAN the mesh network is bridged with the outside world offering connectivity to the SMURFs. The module is based on COTS components and specially developed software. It contains two wireless RF transceivers for redundancy purposes: i) a 2.4GHz ISM frequency band transceiver, suitable for medium bandwidth data transfer, high obstacle penetration and low interference environments in this band, and ii) a 5GHz ISM transceiver, suitable for high bandwidth data transfer and areas with high interference in the 2.4GHz band, but relatively limited in range and material/obstacle penetration. Two WMNs are thereby automatically setup, taking advantage of the combination of the different characteristics of each band. Each station operates in multi-hop fashion. A clever OSI Layer-2 routing algorithm is setup (Open Mesh B.A.T.M.A.N), allowing a dynamic operation where the optimal path is always updated in real time.
- **Speaker** and **microphone**, **visual** and **thermal cameras**, **LEDs**, **sonar rangefinder**, **LiPo battery**, **antenna**: Visual and thermal cameras "bring eyes" inside the rubble pile. LEDs assist the visual camera by illuminating the environment in front of the SMURF. The sonar rangefinder assists the autonomous control system by detecting possible obstacles. The main challenge is to obtain satisfactory performance with COTS components of acceptable size and power consumption.
- **Microcontroller unit (MCU)**: The Raspberry Pi Compute module 3+, in a flexible form factor intended for industrial applications, has been selected for the first version of the SMURF. The MCU runs the control algorithms to achieve autonomous and remotely controlled movements, the localization and communication software, the processing of video and thermal camera images and streams, as well as the analysis of sensor data. The SMURF robotic software and its interface rely on the Robotic Operating System (ROS) 2 framework. The system is designed to display robustness even in the context of an unreliable communication mesh network.
- **Mechanical components**: The mechanical parts of the SMURF include a body sandwiched between two elastic wheels, two motor housings, a tail, and a tail fin. This simple design enables the body to stand in an upright position to gather visual information and the voice of survivors keeping wireless

communication, and the robot to run and drop in debris cones. Improvements compared to the pre-prototype version involve several key aspects: a) component layout re-design, b) durability against shock, heat, vibration, water and dust, c) wide elastic wheels with glossers to improve drop impact resistance and mobility on rough terrain, and ensure static stability when in stand-up motion, d) subcomponent miniaturization and e) larger torque geared motor to climb higher steps, slopes, and obstacles without getting stuck within the rubble (Watanabe et al, 2021).

The first prototype version (V1) of the SMURF along with the arrangement of its components can be seen in Figure 3 (dimensions: 323mm ×326 mm (full length ×full width)). At this stage of the project, SMURF V1 is approaching completion. Hardware testing performed up to now is described in (Watanabe et al, 2021). Five SMURFs will be tested in the lab, and even more in the field in the coming months. The future work will consider the lab and small-scale field test results, and FR feedback. In addition, the possibility to use a mono-wheeled flexible track (Osawa et al, 2020) instead of the soft wheel of the SMURF V1 will be evaluated.

Figure 2. Swarm of SMURFs illustration. The SMURFs are deployed on a rubble pile either manually by the FRs or by the Transport Drone.



(a) SMURF V1.0.4 integrated with components. (b) Travelling mode by two-wheel drive.

Figure 3. SMURF V1.

CURSOR in the air: Drone fleet (DF)

The CURSOR DF enables multi-faceted situational awareness, risk assessment due to damaged structures (e.g. zooming into sections of buildings), transport of specialized equipment (SMURFs, GPR) to inaccessible rubble piles, and communication services (e.g. public alerting and communication with victims through megaphone). The novelty of the DF consists in integrating drones with different sensors, thereby providing a comprehensive assessment of locations of potential survivors under rubble in shorter time and at lower cost than currently possible. At the same time, reducing the risk of bodily harm to first responders. More specifically, the CURSOR DF encompasses the following drones (Figure 4):

- **Mothership Drone (MD)**: tethered drone with HD video camera, flood lights, megaphone and Wi-Fi access point serving as 24/7 “Eye in the Sky” at the disaster zone. The tether is adapted with an additional optical fiber-cable for data transmission to the ground base station.

- **Transport Drone (TD)**: heavy-lifting drone transporting and unloading SMURFs to unreachable rubble piles under remote, wireless control. It is equipped with HD video camera, thermal camera, floodlights and a megaphone, and will fly to locations with high probability of finding survivors.

- **Ground Penetrating Radar Drone (GPRD)**: a drone transporting a GPR sensor which can detect survivors buried underneath rubble. The GPR is transported in a ruggedized container and is lowered to selected rubble piles via a remotely controlled electric winch (Figure 5). The detection is based on the analysis of reflected radar signals. The GPRD can be also used without the GPR for an initial aerial overview of the area with its HD video camera.

- **Modelling Swarm Drone (MSD)**: five drones operating in pre-programmed swarm formation, providing a 3D model of the disaster area based on aerial photogrammetry. Multiple overlapping geo-referenced photos of the area are taken as the drone flies along an autonomously pre-programmed flight path. Such information can support the selection of areas of interest for subsequent operations as well as the assessment of any risks to FRs from potential structural instabilities. The parallel use of five drones accelerates the procedure of capturing the required photographs. There is also the possibility of using these small and compact drones as “pocket drones” for obtaining close-up information of interest at any time during the mission.

At present, the MD, TD and GPRD constitute special configurations of two drone airframes (GAIA 160 and REHA 160). Using the results of continuing tests, the same heavy-lifting airframe will be selected at the end of the project in cooperation with the end-users. MSD is currently based on DJI MAVIC PRO and will be updated to the latest technology towards the end of the project. The selection of COTS equipment for the DF was based on a survey, which analyzed the characteristics of the available equipment in relation to the requirements identified in the project and considered technical excellence, equipment handling, maintenance and cost. The full spectrum of flexibility that USaR stakeholders request for managing the aftermath of an earthquake with the support of drones suggests that a single platform approach is not feasible. Having three drones, though, based on the same drone type reduces maintenance costs, and facilitates training as well as handling. Several of the above drone operations can be performed in parallel by trained FRs.

Two computing stations are used: i) the On-site Drone Server (OSSRV), managing all data associated with operating the drones in-flight (e.g. video streams, streamed GPR and thermal camera data) and also serves as a gateway to the EG so that all data are forwarded to the EXPER system, and ii) the On-Site drone WorkStation (OSWS) carrying out flight path programming of MSD and photogrammetry processing of aerial MSD photographs.

In the current stage of the project, each drone has undergone ruggedization and optimization in terms of safety features, as well as tests under laboratory conditions and in the field, considering various aspects of their operation, including manpower and time required for the various steps of their usage. Payload capacity, energy source, flight characteristics and flight time are linked together through design trade-offs. The results obtained hitherto demonstrate that the DF can be operated in snowstorms, at ambient air temperatures ranging from -5 C to over +30 C, and in heavy rain. The drones can withstand dropping from 30 cm onto tarmac. The DF will be further optimized during the remaining project time, by taking into account the results of tests as well as the feedback of FRs.

For more details about the CURSOR Drone Fleet, the reader is referred to Auer et al., 2020.

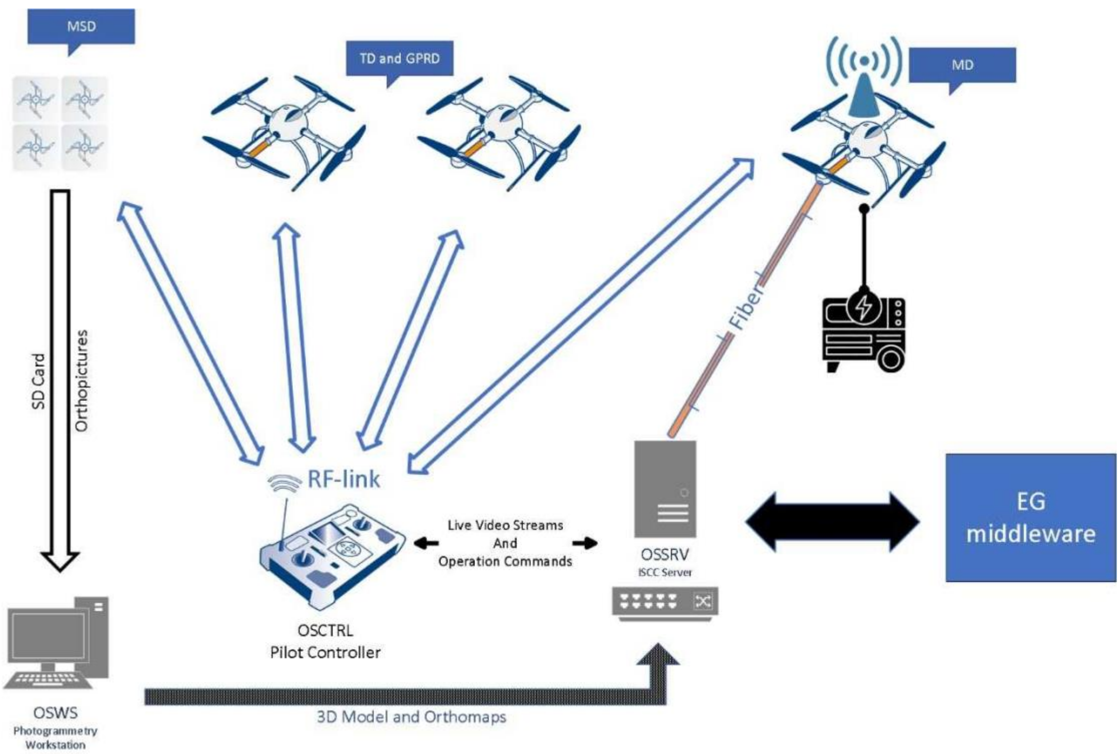


Figure 4. The CURSOR's Drone Fleet System Overview

Figure 5. Ground Penetrating Radar Drone (GPRD)

Geophones

The current technology widely used in USaR missions involves a portable system with two or more geophones and one microphone connected to a recorder through cables. The geophones are deployed around the area indicated initially either by dogs or by other information. They start tapping in regular time intervals expecting the buried person to respond. The recorder indicates the amplitude of the recorded signals with a scale of LEDs. The operator is moving the geophones one by one according to the largest signal strength. Gradually all geophones will be moved in an area of maximum possible signal strength, which is considered the location of interest. Unfortunately, this procedure entails the risk of misleading locations due to possible directivities of the acoustic energy release following some debris structure, and requires a skilled operator to detect converted sound into something of interest. One of the main problems of the current solutions is also the need to move cables over the debris [U.S. Army Corps of Engineers]

CURSOR proposes a cable-less and wireless solution which does away with cable planting across the disaster site as well as the need to move the geophones up to the point of strongest signal. “Stay still” time periods are therefore minimized, thereby increasing the speed of the process and improving the logistics of the detection procedure. To automate the process, a 32bit high resolution digitizer is used, developed recently (Motus Digitizer) to support applications such as geophysics prospection and earthquake early warning, along with very sensitive geophone sensors that can record very low amplitude ground noise. A geophone kit consists of the digitizer and an array of three geophones forming a triangle within a small distance from each other. Array-based techniques are used for noise source detection. We can have the noise source estimation even by one array, but if using two arrays, the noise source can be better constrained. The introduction of phase arrivals estimators is expected to help avoid directivities of energy release. Both noise amplitudes and phase info are assessed, and all analyses are implemented locally in the ruggedized tablet, which estimates based on the selected time window, the vector to the source along with an error estimate. The operator can visualize the vectors, from at least two geophone kits where the indicated sources of noise will be processed and visualized in the form of a hot zone. This observation can be sent to EXPER to fuse or propagate to the COP Terminal and COP.

Information Management: Multi-source Data Fusion Engine (MDFE), Expert Reasoning Engine (ERE)

The CURSOR’s data fusion and event processing engine, EXPER, comprises two logical components: (MDFE, ERE) that cooperate to provide (near) real-time worksite information to the Common Operational Picture components of the Kit. Machine learning (ML) techniques are used to increase situational awareness and improve the accuracy of victim location alerts. An ML-based data fusion approach is introduced, based on cutting-edge technologies and sophisticated algorithms to address data fusion challenges effectively with respect to criteria such as efficiency, quality, stability, robustness and extensibility (Meng et al., 2020).

The heterogeneous CURSOR sensing data is transmitted to the EXPER, through common standards. The CURSOR Data Model follows the SensorThings standard of the Open Geospatial Consortium (OGC). For alert exchange the OASIS Common Alerting Protocol (CAP) is adopted.

Based on their source, the data are forwarded to different topics of an Apache Kafka message bus. A microservice consumes all data, validates and stores them to the database. For high-volume data the SSH File Transfer Protocol (SFTP) is used, to allow secure and reliable data exchange. In the case of video streaming, the list of streams is advertised by the media server of the OSSRV and fetched by EXPER, which in turn shares it with the COP. On demand streaming of stored videos to the COP is available through EXPER's media server.

The ERE subscribes to topics of the message bus to retrieve data for extra processing and publishes the results in order to be communicated to the COP. The processing of the data includes aggregating, correlating and displaying such information. Orthophotos and 3D area models produced by the drones are analyzed in order to detect openings that can serve as entry points to the rubble for the SMURFs.

For victim location identification the DBSCAN clustering method (Li, 2020) is used, a promising method, robust in noise and outliers, for discovering clusters of different shapes and sizes from a large amount of data. The Convex Hull algorithm is used to achieve the maximum parsimony for the area of operations. Intersect Convex hulls combine Sniffer with geophones measurements to suggest an area of interest. The proposed ML-based data fusion approach represents a concept that has not been extensively researched in the literature. It seems to be very promising as our first computational results are associated with high performance measures, providing FRs with useful recommendations for decision-making purposes.

Visualization and Incident Command Modules: Common Operational Picture (COP) and COP Terminal (COPTERM)

The COP component resides at the UCC site, where higher command personnel operate, and is a workstation that ultimately assimilates information from all CURSOR sensors. It supports incident coordination and provides the overall operational view to be shared among involved actors, thereby enhancing situational awareness. It constitutes an integrated solution to visualize the worksite environment and the operational information in an informative and intuitive way. The offered features will include: user management, resource and specifically equipment management, creation of incidents, assignment of teams and equipment to incidents, creation of areas of interest and assigning the teams and equipment to these areas, receiving alerts (possible victim locations) and sensor operation status from the EXPER system, tabular views, 2D and 3D maps (and various tools for the maps).

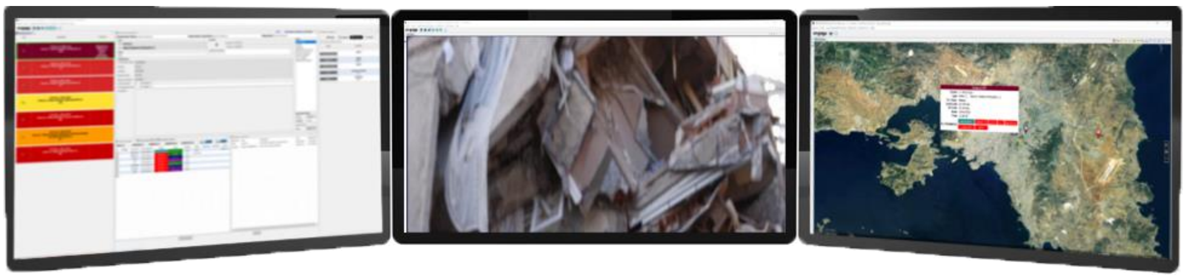


Figure 6. Using the COP in USaR

Figure 7. COP Terminal

The COP Terminal comprises both a hardware and software solution. The hardware to be used will be a ruggedized tablet capable of running Microsoft Windows (location sensors, front and back facing cameras, battery hot-swap, touch-enabled both with gloves and fingers, stylus). On the software side, a mobile version of the ENGAGE platform (ENGAGE), offering the following features: user authentication with the COP, ability to run in offline mode (if there is no connection to the COP), visualization of assets, sending photographs to COP, sensors and detected survivors in the field in a 3D map, taking visualization of camera feeds from sensors, visualization of the 3D model of the disaster site as generated by the MSD, communication with COP and entering worksite information.

The COP and COP Terminal provide a rich situational awareness tool for FRs to visualize their equipment and their outputs in one single system thereby helping decisions to be made, such as where to concentrate resources and efforts.

An investigation will also take place to determine inter-operability at the field level with Survey 1-2-3 / INSARAG.

CURSOR Secure and Resilient Worksite: the Emergency Gateways

A robust, rapidly deployable and reliable wireless communication solution is required in order to support USaR missions in a smooth and efficient way. Resilience to the harsh disaster environment relates to a number of factors such as rough handling, interference, signal attenuation, absence of cellular networks, etc. In addition, the system must be capable to support bandwidth-intensive worksite data.

A custom communication solution has been designed and developed for the post-earthquake debris environment, comprising two central communication gateways (one at the worksite and another one at the UCC), which integrate different communication interfaces for redundancy purposes. The design is based on widely available, low-cost silicon technology considering requirements for improved performance, decreased size and weight, cost and power consumption.

A long-range wireless link is established between the two central gateways, while portable gateways bridge the WMN set up among SMURF team members, operating at specific rubble piles, with the rest of the network infrastructure (Figure 8). Each SMURF targets the absolute minimum size in order to operate in a confined space, which translates into critical antenna size and power usage considerations. Thus, the SMURF teams are using mobile device grade antennas and the portable EGs in their vicinity bridge the gap with the rest of the network via larger antennas and transmit power. The mesh networking approach facilitates traffic inside the rubble pile via mesh node multi-hopping, which can route traffic outside by using a chain of SMURFs (see also SMURF section).

The EG systems constitute easy to deploy, modern computing platforms that integrate all required communication technologies in a small factor mobile device inside a rugged case. The goal of the EG is to provide seamless interoperability and ubiquitous connectivity via Wireless Ad-Hoc Networking, security by design on all communication channels using the latest open standards (authentication, encryption), and resilient operation. The CURSOR EG serves also as a gateway to the World Wide Web, using two cellular LTE modems for 4G Internet access. Different Internet Service Providers in each modem allows extra resiliency in case of coverage failure. An external mobile satellite communications modem has been foreseen as well for cases when the cellular internet infrastructure is damaged. Wired Ethernet connections are also offered, while a UPS supports continuous operation during petrol generator refueling.

At the current stage of the project, the first version of the communication solution has been implemented and successfully tested in lab environment.

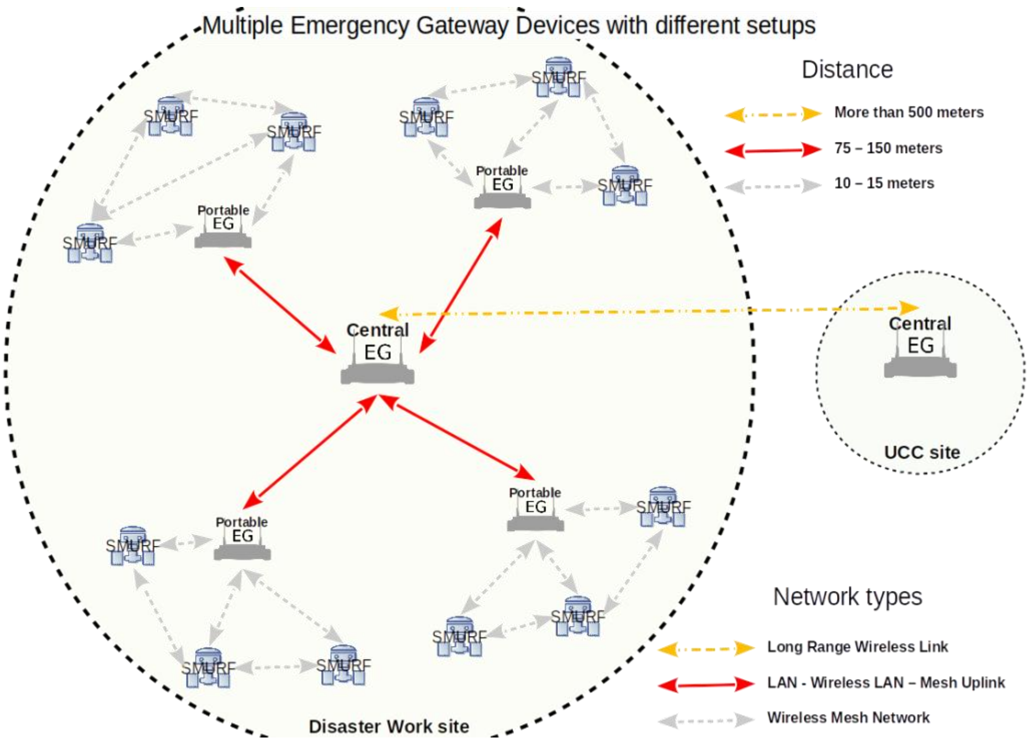


Figure 8. Multiple EG devices with different setups

TESTING AND INTEGRATION

In order to develop and test a complex SaR Kit, integrating many heterogeneous hardware and software technologies, early and iterative integration testing and functionality validation is a prerequisite. A continuous integration and validation plan has been designed for CURSOR. The integration and validation activities proceed incrementally and iteratively from internal laboratory tests of single components to collaborative lab tests of multiple integrated components, as the development process advances, and from lab environment and remote testing to Small Scale Field Tests (SSFT) and Large Field Trials in realistic environments. Approximately 6 lab tests, 10 SSFTs and 2 CURSOR SaR field trials will be conducted to develop an easy and quickly deployable SaR Kit of integrated technological components which directly respond to the FR needs (currently 4 lab tests and 1 SSFT have been conducted). Initial testing results available up to now have been concisely integrated in the sections describing the individual components.

CONCLUSION

Although a number of mature and emerging technologies for USaR exist, most approaches and systems have not been systematically tested and validated in applications involving collapsed structures (Statheropoulos et al, 2015). It is becoming increasingly evident that the integration of multiple technologies offering complementary capabilities to an USaR system can enhance efficiency and reliability during operations. This complementarity principle lies at the heart of the CURSOR project approach.

Overall, the CURSOR SaR Kit follows a modular, interoperable and integrated framework, built around automated and easily deployable platforms that are equipped with a multitude of sensing, actuation and control components used in the disaster scene for providing rich sets of continuously updated information, scanning and mapping the worksite area, within and around a damaged building. These platforms are closely interconnected over reliable and resilient communication means to each other, to local processing units and to a middleware fusing and reasoning all information captured in and around the worksite. The data are ultimately visualized over 2D/D Geographical Information System (GIS) in order to enable coordinated tactical command.

The CURSOR SaR Kit has been designed to reduce the time for USaR teams in detecting and locating trapped victims in disaster areas, improve the protection of FRs safety, and reduce the time for the deployment of USaR personnel and equipment, situational assessment and on-site disaster response.

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