SMART BOOTS, FUSION ENGINE AND AERIAL ASSETS FOR ENHANCED SITUATIONAL AWARENESS AND SAFETY IN SEARCH & RESCUE OPERATIONS

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ABSTRACT
Innovative technologies can enhance operational capabilities of First Responders (FRs) during Search & Rescue (SAR) operations, while at the same time increasing safety levels. The INGENIOUS project[1] (EU Horizon 2020) aims at developing, integrating, testing and validating a next generation SAR toolkit for collaborative response, which ensures high level of protection and augmented operational capacity in disaster situations. In this paper, a subset of components of the toolkit mostly focused on increasing situational awareness and safety are described: the Fusion Engine (FE), which receives data from multiple sources, stores and analyzes them for integration purposes regarding situational awareness and sends them to the Common Operational Picture (COP) as well as the mobile FR terminals; the Smart Boots (SB), which collect data of individual FRs and provide information regarding their health status and alerts; the Modular Airborne Camera System (MACS); the Multi-purpose Autonomous eXploring (MAX) drone for indoor/outdoor mapping and assessment of unknown environments; and the Micro INdoor drones (MINs) used for FRs indoor localization. The functionalities of these components, as well as the first prototypes developed and currently under lab and field test, are presented in this paper.

Keywords: Search and Rescue (SAR), fusion engine, smart boots, Unmanned Aerial Vehicle (UAV), drone, first responder, tactical awareness.

1. INTRODUCTION
As technology advances, innovative technologies for SAR operations are developed and tested from public safety agencies. One of the core requirements to improve the efficiency of these operations is

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enhancement of situational awareness, both for the FR teams and the Command Center. On the other hand, due to the high risk of exposure in hazard and life-threatening situations, FRs' mandate for safety is crucial. As part of the INGENIOUS project [1], we develop a SAR Toolkit, which aims at improving situational awareness, while setting FR safety as a first priority.

In this paper, a partial list of the SAR Toolkit components is presented, mostly focused on providing enhanced situational awareness and safety but not exclusively; the Fusion Engine (FE), which acts as a bridge between the operations on the field and the commanders, providing functionalities related to collection and analysis of data and information; the Smart boots (SB), which collect data and biometrics of individual FRs and provides information regarding the health status; the Modular Airborne Camera System (MACS) carried by a fixed wings drone that has extended flight time capacity and speed in order to deliver a large-scale mapping of the disaster area; the Multi-purpose Autonomous eXploring (MAX) drone for indoor/outdoor mapping and assessment of unknown environments; and the Micro INdoor drones (MINs) used for FRs indoor localization.

2. FUSION ENGINE (FE) AS THE FOCAL POINT OF DATA FROM MULTISENSORY DEPLOYED SYSTEMS

The FE is the focal point where all received data collected from the INGENIOUS sensors and applications are gathered, stored, and collectively processed. By processing those data sets, the FE extracts valuable information regarding the tactical situation and the FRs' health status. There are two main tasks for the FE (see Figure 1): (1) Collect, validate and store and forward data to the Expert Reasoning (ER) modules and remote services for decision support and early warnings generation. A distributed streaming platform (Apache Kafka) is used for real-time data handling allowing publish/subscribe to streams of records, store streams of records in a fault-tolerant way, and process streams of records as they occur; (2) Process and merge the collected data to create increased situational awareness and support decision making for the operation. A workflow management system (Apache Airflow) manages and monitors the scheduling and execution of all internal tasks. Fusion depends on the particular data characteristics while data correlation between different sources requires metadata such as timestamp and georeferenced location.

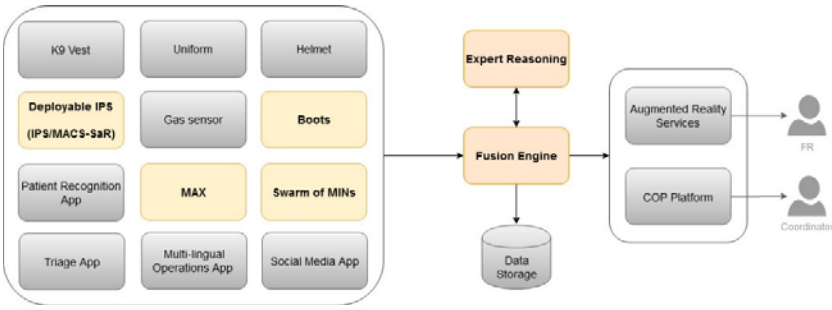

Figure 1. Overview of the FE: Collect data, validate and store, perform fusion via smart algorithms and present them to FR and commanders for increasing their situational awareness.

So far, the functionalities provided by the FE include: (a) **Map zone classification**, where danger areas of worksite where increased temperature and dangerous gases have been identified will be shown as colored zones aiding the situational assessment; (b) **Areas of interest identification**, in which unvisited places/rooms of buildings will be identified, marked and displayed accordingly to facilitate the coordination among FRs; and (c) **FRs health warning system**, in which monitoring and assessing the health status of FRs will take place and produce alerts when warning health levels are reached or when safety protocols are not adhered.

3. SMART BOOTS (SB) FOR HEALTH STATUS MONITORING

The SB component is a novel situational awareness tool for FR and SAR operations. The operational FR safety boots become smart with the use of custom-build electronic multi-sensor insoles. Hosting several embedded sensors in the wearable insole form factor, SB can inform the FR or (via the FE) the team leader, in real time, about the health status of an individual team member while operating in the field. A warning or alert can be raised based on the information collected from the sensors. Sensors like accelerometer, gyroscope and magnetometer are responsible to determine the orientation of the FR. In addition, flexible force sensors are used to determine if a FR is putting pressure on the insole as well as the force distribution across each foot. Edge processing algorithms combine and analyze all sensor data to detect any irregularities or inconsistencies that will raise appropriate alerts, e.g. prolonged immobilization or asymmetric walking indicating injuries, or excessive force combined with high g-forces indicating a dangerous fall. The electronic insoles are battery-powered and can be charged wirelessly without the need to remove from boot. The use of low-power electronics and communication modules allow autonomy for long missions on a single charge.

4. AERIAL ASSETS FOR ENHANCED POSITIONING AND ASSESSMENT OF UNKNOWN ENVIRONMENTS

Within INGENIOUS, a combined on-ground –and drone multi-sensor system for FR real-time localization and rapid environmental mapping is developed. This enhances the FR orientation capabilities in the field and leads to better sounding, investigation and documentation of structural fault, e.g. damaged buildings after an earthquake. The Integrated Positioning System (IPS) device carried by FRs, estimates the FR position in action in a combined indoor and outdoor environment while performs a smaller scale environmental mapping. Aerial assets contributing at different levels towards the direction of indoor and outdoor mapping, localization and positioning of FRs/assets are described in the following.

(a) (b) (c)

Figure 2. (a) MACS Camera system module mounted in front of the fixed-wings drone, (b) MAX under development, (c) The Crazyflie 2.1 platform used for the MINs.

4.1. Modular Airborne Camera System (MACS) for large scale area mapping

While the IPS is used indoors to provide small scale mapping, the complementary Modular Airborne Camera System (MACS) that equips a a vertical take-off and landing (VTOL) fixed-wing drone is deployed to associate previous data and provide large scale mapping. Based on a metric camera system, the first prototype of the drone-based real-time mapping camera incorporates an industrial camera, a dual-frequency GNSS (Global Navigation Satellite System) receiver including inertial-aided attitude processing (INS), and an embedded computer responsible for time synchronization, image acquisition and real-time image processing. In this configuration the system allows to capture up to 4 raw images per second which can be stored on a removable storage device. The weight is 1.4 kg (including embedded PC, camera, IMU, GNSS receiver, GNSS antenna, power management and structure) and the dimensions are 10 x 14 x 20 cm^3. A fixed-wing drone (see Figure 2 (a)) is used as carrier providing a flight time of approximately 90 minutes at cruise speeds between 80km/h and 140km/h. Thus, the carrier is capable to travel a distance of up to 105 km per battery charge. It is specified with maximum takeoff weight of

14kg including a payload of up to 2 kg and has a wingspan of 3.5 m. It can operate at wind speeds of up to 8 m/s and temperatures between 0°C and 35°C. While its typical flight operation altitude is in the range between 100 m and 300 m above ground level, it is capable of operating at altitudes up to 3,000 m above sea level. The operational range is only limited by the maximum flight time because the autopilot system allows fully automated flights beyond visual line of sight (BVLOS).

4.2. Multi-purpose Autonomous eXploring (MAX) drone for indoor/outdoor mapping

The MAX is the FR's extra companion that assists in the exploration and assessment of potentially dangerous buildings. Using a variety of sensors and an on-board distributed computational system, MAX will be able to navigate and explore an environment completely on its own while sending multi-sensor data (video, infrared images, gas sensor readings, temperature measurements, etc.) to a ground control station where it can be visualized and processed further. By creating 3D maps and locating itself in the previously unseen environment, MAX will keep track of explored and unexplored areas and optimize data collection to avoid over-assessment of previously visited places and to highlight the parts of the buildings where MAX could not reach or its sensors were not able to observe. In essence, MAX gives the FRs a detailed look inside the building while they are busy doing other things.

MAX airframe size is 43 x 43 cm^2, with a payload capacity of about 600 grams (battery excluded). The maximal flight time of a fully loaded platform of this size is limited to 10-15 minutes. The MAX with some of its sensors is presented in Figure 2 (b); a 360 degrees lidar (laser scanner), a forward-looking stereo camera and a number of sonars used for navigation and obstacle avoidance, visual and thermal cameras used to supply data for building assessment and scene understanding.

4.3. Micro INdoor drones (MINs) for indoor localization

The MINs are intended as small and disposable devices to aid the indoor localization (GPS denied environment) of the FRs (see Figure 2 (c)). The MINs will achieve this objective by working in a swarm fashion, that is, a group of MINs will enter the building before the FRs and will disperse within the building in order to create a mesh network which will be used to localize the FRs in the building by triangulation techniques. Each MIN will be a node of the mesh network and each MIN will carry an Ultra-Wide Band (UWB) beacon to be used to localize the FRs wearing a UWB receiver.

The MIN size is 9 x 9 cm^2, weights 27 grams with a payload of 15 grams and provides of almost 7 mins of flight. Each MIN is equipped with: UWB sensors: to track the motion of an FR carrying an FR receiver within the building; Ranger sensor: laser sensor to sense obstacles nearby and avoid them while flying; An optical camera: pointed downwards to support odometry and estimate the position of the MIN.

5. CONCLUSIONS

The INGENIOUS components presented in this paper are developed and customized for use within the context of real-world SAR operations, enhancing situational awareness and safety. The highly demanding environment of such operations requires improved performance and autonomy. The INGENIOUS project SAR Toolkit will provide such technologies, which are already prototyped and currently under ongoing lab and field tests.

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