ICARUS: Providing Unmanned Search and Rescue Tools

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***Abstract*—The ICARUS EU-FP7 project deals with the development of a set of integrated components to assist search and rescue teams in dealing with the difficult and dangerous, but life-saving task of finding human survivors. The ICARUS tools consist of assistive unmanned air, ground and sea vehicles, equipped with victim detection sensors. The unmanned vehicles collaborate as a coordinated team, communicating via *ad hoc* cognitive radio networking. To ensure optimal human-robot collaboration, these tools are seamlessly integrated into the C4I equipment of the human crisis managers and a set of training and support tools is provided to them to learn to use the ICARUS system.**

***Index Terms*—Search and Rescue, Robotics, C4I**

I. Introduction

Recent dramatic events such as the earthquakes in Japan, Haiti and L'Aquila or the flooding in Pakistan have shown that local civil authorities and emergency services may have difficulties with adequately managing crises. The result is that these crises lead to major disruption of the whole local society.

The goal of ICARUS is to decrease the total cost of a major crisis. In order to attain this goal, the ICARUS project proposes to equip first responders with a comprehensive and integrated set of unmanned search and rescue tools, to increase the situational awareness of human crisis managers, such that more work can be done in a shorter amount of time.

As every crisis is different, it is impossible to provide one solution which fits all needs. Therefore, the ICARUS project will concentrate on developing components or building blocks that can be directly used by the crisis managers when arriving on the field. Furthermore, the project aims to provide an integrated proof-of-concept solution, to be evaluated by a board of expert end-users that can ensure that operational needs are addressed.

In the event of large crises, a primordial task of the fire and rescue services is the search for human survivors on the incident site. This is a complex and dangerous task, which, too often, leads to loss of lives among the human crisis managers themselves. The introduction of unmanned search and rescue devices can offer a valuable tool to save human lives and to speed up the search and rescue process. Therefore, ICARUS concentrates on the development of unmanned search and rescue technologies for detecting, locating and rescuing humans. In this context, there is a vast literature on research efforts towards the development of unmanned search and rescue (SAR) tools, notably in the context of EU-sponsored projects. This research effort stands in contrast to the practical reality in the field, where unmanned search and rescue tools have great difficulty finding their way to the end-users, due to a number of remaining bottlenecks [4] in the practical applicability of unmanned search and rescue tools.

The ICARUS project addresses these issues, aiming to bridge the gap between the research community and end-users, by developing a toolbox of integrated components for unmanned search and rescue. The objective of the ICARUS project is to develop robots which have the primary task of gathering data. The unmanned SAR devices are foreseen to be the first explorers of the area, as well as in situ supporters to act as safeguards to human personnel. In order not to increase the cognitive load of the human crisis managers, the unmanned SAR devices will be designed to navigate individually or cooperatively and to follow high-level instructions from the base station. The robots connect wirelessly to the base station and to each other, using a wireless self-organising cognitive network of mobile communication nodes which adapts to the terrain. The unmanned SAR devices are equipped with sensors that detect the presence of humans and will also be equipped with a wide array of other types of sensors. At the base station, the data is processed and combined with geographical information, thus enhancing the situational awareness of the personnel leading the operation with in-situ processed data that can improve decision-making. The Haitian experience has shown the importance acquired by the geographic component in the management of human and technical resources in crisis situations. Similarly, it has highlighted that a suitable distribution (through interoperable standards) and real-time generation of thematic maps (demolished buildings, destroyed bridges, etc.) allows optimisation and interoperability of these resources and accelerates the access to victims. All this information will be integrated in existing C4I systems, used by the forces involved in the operations (e.g. fire fighters, rescue workers, police, etc.).

In line with the current bottlenecks [4], eight main objectives are defined for the ICARUS project. These objectives address the operational needs of rescue and civil protection services. These objectives are discussed in the following sections of this paper.

II. Development of a light sensor capable of detecting human beings

A primary task for crisis management teams after the occurrence of a large disaster is the search for human survivors at the incident site. These survivors must be found as soon as possible in order to maximise their chances of survival. However, when confronted with a large-scale crisis, the manpower is often lacking for such a widespread search. In this case, unmanned vehicles equipped with victim detection technology can help the search operations. For human survivor detection, infrared sensing technology seems the most adequate detection tool. In this sense, in the last couple of years, several successful concepts for IR sensors have been developed. For the detection of human survivors in a disaster situation, an ultra-high sensitivity in the mid-IR wavelength range is absolutely crucial. Photovoltaic low-noise detectors such as the quantum cascade detector (QCD) [5] are very well suited to fulfill this requirement and should therefore be developed.

The objective of ICARUS is the development of a small light-weight camera system capable of detecting human survivors. These prototype cameras will have a resolution of 128x128 pixels arranged in a small array of 2x2 single chips. They will be based on novel and very promising QCD technology. The latter will allow the manufacture of highly sensitive, low noise, narrow band IR detectors with a detection wavelength of 8 µm. This ultra-sensitive, but relatively low-resolution QCD camera will be complemented by a commercial high-resolution lower-sensitivity micro-bolometer camera. Minimal levels of weight (500 g), dimensions (12x12x6 cm) and total power consumption (5 W) are being targeted. Image and video processing algorithms for detecting human survivors will be developed and combined to obtain sufficient detection performance. Data fusion methods will be applied to images coming from different cameras, resulting in different detection algorithms.

III. Development of cooperative Unmanned Aerial System (UAS) tools for unmanned SAR

The importance of gaining an overview within the first one to two hours in the particular case of an earthquake is a strong requirement for end-users. The end-users underline the important role Unmanned Aerial Systems could provide in this context by providing continuous support to coordinators and operators in the field.

- Mapping of topography and scenario. This information is the basis for situational awareness and planning of both unmanned as well as manned missions.
- Target observation. This allows an operator to quickly send a camera to a specific position and attitude as a “remote eye-pair” including tracking and following a moving “target”.
- People search outdoors and indoors. The use of dedicated computer vision algorithms on-board the UAS will firstly allow for the localisation of bystanders/victims within an acceptable range of precision; and secondly, for tracking them, then adapting the navigation and aid kit delivery. Both features reduce workload as compared to existing manned search. This on-board capability is complementary to coordination and field teams as well as C4I equipment that can process more accurate localisation information.
- Kit delivery. Once localised, victims may not be quickly reachable by search and rescue teams due to distance (e.g. at sea), weather conditions and so forth. In this case, the UAS can deliver light first-aid kits, such as self-inflating emergency floatation devices to provide the victim with first emergency response.
- Communication relay. Maintaining or deploying a ground communication network in remote areas can become cumbersome or unfeasible; UAS platforms can instead act as relays.

UAS platforms will be given a crucial role by acting as quick deployment assets in the field to provide valuable information to enhance situational awareness in support of the assessment of crisis managers, as well as to enable tactical planning and decision-making. This aerial infrastructure will also provide continuous support to coordinators and operators in the field, complementing the UGV and USV solutions. UAS platforms will be equipped with sensors tailored to SAR requirements, including the IR camera and victim detection algorithms, allowing for the localisation and tracking of victims. In order to meet the above demands, complementary platforms are proposed:

- A small long-endurance solar aeroplane [6] (3m wingspan) is meant to provide the highest view at a maximum height of 300m, as allowed by national legislation, and therefore enabling the mapping functionality and initial victim search. Payload other than small cameras is limited, but operation times span up to a day. With shorter range and endurance (half an hour maximum), but closer to the ground and the victims, three rotary wing systems are to be deployed.
- A Quadrotor with a size of 1m and a maximum payload of 1kg will be used for delivery tasks outdoors and observation.
- A slightly smaller Multicopter will be used for indoor people search. Consequently, on-board autonomous functionalities will be developed to decrease the operator workload and increase the operational efficiency in the overall C4I system.
- Finally, an innovative “Gyropendulum” system, with a similar size to the Quadrotor, featuring more control authority, will be used for delivery in rough weather conditions in a semi-autonomous way.

IV. Development of cooperative Unmanned Ground Vehicle (UGV) tools for unmanned SAR

End-users expressed the need for two types of robotic platforms in SAR operations:

- A large UGV which can be used as a mobile base, equipped with ample sensing capabilities, broadcasting the data it collects towards the field operators, as such increasing their situational awareness. A crucial requirement is that this vehicle should be able to cope with rough terrain.
- A small UGV which is able to enter in collapsed buildings to search for human victims, an extremely dangerous but also life-saving task.

The ICARUS project considers the production of the aforementioned types of robotic systems, using existing base platforms.

The Large UGV (LUGV) that shall be part of the ICARUS project shall serve as a platform fulfilling several central tasks. After being deployed close to the site of an emergency, it shall move in a semi-autonomous way in a potentially hazardous and unknown environment. Within this context, three different roles of the large UGV can be envisaged:

- Mobile sensor platform. Gathering a large amount of precise data is necessary for (semi-) autonomous navigation in challenging environments [2] as well as for the support of emergency teams. Such data can only be collected partially by UAS as they are small and lightweight and therefore not able to carry more sophisticated sensor systems. The large UGV shall be equipped with different sensor systems in order to account for the large variety of environment types the vehicle will possibly encounter.
- Platform for powerful manipulator. The UGV shall be equipped with a powerful manipulator that can be used to clear the vehicle's path from obstacles like small debris. It could also be used to lift objects if a victim is buried beneath them. Furthermore, the manipulator shall be used to deploy the small UGV on the ground or even on higher structures such as the first floor of a collapsed building.
- Transport platform for small UGV (SUGV). The UGV serving as a platform will have to carry several sensor systems and be powerful enough to surmount large obstacles. Therefore, it will be too large to drive into collapsed structures without the risk of causing even more damage or injuring victims. Hence a smaller UGV shall be carried by the platform and deployed in the site to gather more information about areas which the LUGV cannot reach.

The LUGV will be powered by a combustion engine and moved by a chain-drive for maximum manoeuvrability on difficult terrain. The planned maximum speed is 25km/h. For localisation purposes, the platform will possess an inertial measurement unit (IMU) and a satellite-based localisation system. The external sensor systems with which the LUGV will be equipped comprise two bumpers at the front and the rear of the system, a panning laser system for near-range terrain analysis that is also able to detect obstacles close-up in front of the robot, a stereo system, and an array of time-of-flight cameras. The victim detection sensors will be mounted on the platform. The manipulator will be designed as 6-axis robotic arm that can lift up to approximately 250kg. Different tools will be provided and carried along on the LUGV. The arm shall be controlled by an exoskeleton, making the integration of torque sensors or pressure sensors in the cylinders for force feedback necessary. A camera shall be added to provide image data for a tele-operator.

The SUGV will be equipped with a propulsion system allowing it to manoeuvre in highly unstructured environments like collapsed buildings. Due to restrictions of size and weight, the vehicle can neither be equipped with sophisticated sensors nor with a powerful computation unit. Hence its autonomous capabilities will be limited to a very low level. A camera will be mounted on the SUGV, so a tele-operator can use it as a remote eye to gather information about the site of the disaster.

V. Development of cooperative Unmanned Surface Vehicle (USV) tools for unmanned SAR

Aquatic search and rescue operations face natural challenges since survival times of people in water are short, even in temperate climates. Furthermore, the risk for search and rescue teams has to be taken into account when deploying assets. Examples are accidents occurring during the night, under low visibility conditions, or under severe atmospheric or sea conditions, for which a fast response might put the search and rescue teams in great danger. For such operations, unmanned surface vehicles, capable of transporting search equipment and deploying first assistance devices, can reduce the arrival time at the incident area of basic life support equipment. At the same time, traditional life rafts that provide survivors with floatation and thermal insulation can be robotised so that they can move autonomously and get close to survivors in the water, therefore reducing recovery time.

This project proposes two main lines of work in order to address the identified demands. On one hand the project will present the instrumentation of a survival capsule to allow its motion towards survivors at the surface. On another hand the project will undertake the adaptation of a medium size USV [7] for search and rescue operations.

Existing survival capsules that usually inflate when deployed allow survivors to climb aboard providing extra floatation and thermal insulation. The incorporation of power generation capabilities, a minimal set of instruments, basic communication equipment, and motion capabilities on board these capsules, will increase the lifesaving capabilities of such devices allowing their use in scenarios with reduced accessibility for other search and rescue services.

USVs, as unmanned systems, allow remote human intervention under severe environmental conditions without putting additional people at risk. They have, therefore, a large potential for search and rescue operations at sea, especially under bad weather conditions with low visibility. Here, the adaptation of USVs for search and rescue will be pursued along the following lines:

- *Sensing and perception*. Gathering data from different sensors installed on board the USV or from external data sources and combining it for target detection and tracking.
- *Mission planning and control*. Mission planning for operations with single or multiple vehicles. Obstacle avoidance manoeuvres.
- *Capsule deployment system*. Provide the USV with the capability of transporting and deploying lifesaving rafts in the incident area.

Furthermore, it should be mentioned that issues related to safety of people, space-sharing between manned and unmanned vessels, and other issues connected to the operation of unmanned vehicles in real-life scenarios will be taken into account both at the sensing and control levels.

VI. Heterogeneous robot collaboration between Unmanned Search And Rescue devices

The main concepts of interest for the end-users include the applicability of a Network Centric Operations paradigm, and compliance and compatibility with existing C2I/C4I systems.

This objective is focused on a key enabling technology concept for the safe integration of autonomous platforms into search and rescue operations: the heterogeneous network. In this sense, the project specifically addresses the intrinsic capabilities and characteristics of a given platform, and how these characteristics are communicated, understood, and exploited by the rest of the SAR system (including human teams, infrastructures, and other autonomous vehicles within the ICARUS integration concept).

In one sense, the heterogeneous network integration and management forms a central layer, with low-level control issues of specific vehicle types beneath it and mission-level planning, coordination and supervision at a higher layer.

The present objective therefore addresses the integration of heterogeneous teams into a single, unified, interoperable system through establishing and demonstrating the interactions and use cases of different vehicle types. The application of search and rescue influences the definition and interactions of the network, and this project objective addresses the following challenges:

- interoperability issues shall be considered through the implementation of standardised interfaces;
- robust definition and specification of tasks, and roles and responsibilities between the autonomous capacity of the heterogeneous team and the mission-level tasking and supervision of the C2I system in network-centric operations (NCO);
- Coordination between multiple UAS in a SAR task;
- Coordination between multiple USV in a SAR task;
- SAR mission operations demonstration integrating a UAS and UGV in a SAR task where the UAS provides support to the UGV;
- SAR mission operations demonstration in which UAS and USV platforms support each other mutually.

VII. Development of a self-organising cognitive wireless communication network, ensuring network interoperability

SAR operations demand proper communication assets to ensure a highly available, real time networking capability for human and robotic teams working in SAR situations with hostile operational conditions. In particular, the following aspects have been identified as key requirements in SAR:

- Mobile and wireless communication capability for all of the involved entities (humans, robots, control centre) with minimum deployment and coordination effort
- Individual and group communications with guaranteed quality and prioritisation capability
- High capacity and range, security and power efficiency

No single technology currently supports all of the requirements at the same time [8]. Thus, several technologies must be used simultaneously, which brings in a new and key requirement: interoperability. Multiple proprietary or standard based networks make it virtually impossible for different entities to cooperate efficiently if communication/network interoperability is not properly addressed.

ICARUS will develop a network infrastructure which adapts to and, at the same time, takes advantage of the peculiarities of the posed SAR scenarios. A holistic approach will be followed, reusing state-of-the art solutions conveniently and focusing investigation on unsolved challenging issues:

- Mobile and wireless ad-hoc communications in combined land-air-sea environments with robotic and human actors, supporting both Line-of-Sight (LOS) and non-LOS scenarios.
- Self-coordination and optimisation of spectrum resources by using cross-layer cognitive radio techniques maximising network usability and minimising interferences.
- Self-managed network able to adapt to varying and extreme conditions by using power-efficient, failure-resilient protocols (e.g. active routing, data-replication, store-and-forward) and convenient guidance of robotic network nodes with specific communication capabilities.
- Flexible security scheme providing granular encryption, integrity and authentication.
- A harmonised management and control overlay on top of a highly robust waveform, able to encompass several data-link technologies (WLAN, GSM) ensuring interoperability.

VIII. Integration of Unmanned Search And Rescue tools in the C4I systems of the Human Search And Rescue forces

Three main action points were identified by the end-users in the context of this objective:

- collection of data/information from the robots, operators, human teams deployed, (and bystanders/rescued victims);
- collation and merging of data from different sources, including allowing for differing reliability of sources and integration with GIS information;

- monitoring and control interfaces that can provide high level (mission or objective level) command capabilities to appropriate users, as well as allow for the publishing / dissemination of new information/mission updates.

ICARUS aims at developing (robot) platform independent monitoring and control capabilities that will be able to handle, process and integrate a wide variety of data flows coming from sources such as the robotic platforms' sensors, human beings (bystanders) in the field, GIS displaying a priori knowledge about the intervention field, etc. The resulting information and knowledge will primarily be exploited at the C2I application level, in order to effectively provide human operators with a high level of awareness allowing them to lead the robotic activities in a coordinated way with humans on field activities.

As a noticeable feature, the C2I control centre will provide a haptic tele-presence workstation allowing real-time control of haptic compliant robotic arms. This interface will in practice be demonstrated with a medium size hydraulic arm mounted on a UGV platform; with suitable control interfaces [3].

The C2I application will allow the monitoring and control of heterogeneous robotic platforms including UAVs, UGVs, USVs, and potentially other types of mobile platforms.

The C2I will be designed to promote interoperability of the controlled systems, as well as aiming for seamless integration into existing infrastructure and applications used by first responders. The C2I development will come as an adaptation of, and integration with, a number of complementary existing technologies that partners will make available for the purpose of the project.

IX. Development of a training and support system of the developed Unmanned Search And Rescue for the Human Search And Rescue teams

Technological tools are no good for the human crisis managers if they do not know how to handle them. Therefore, an extensive training and support infrastructure is required. Training with the use of computer simulation finds its application in increasingly more areas, both for obtaining and perfecting skills to operate machines (in the domains of aviation, railroads, road vehicles, heavy equipment, etc.) as well as manual skills - often with the use of haptic feedback technology – primarily in medicine. An important trend consists of designing trainers-simulators of the PC-type, and enabling e-training with the use of the Internet [1]. In the case of technological tools for search and rescue, such an infrastructure does not exist and is urgently required.

The problem of using PC-type trainers-simulators for training operators of inspection-intervention mobile robots is to be extended for training in unmanned SAR activities in ICARUS. From the support system's point of view, new software tools related to training can be directly applied for operator support. It is a new concept of providing software tools that can be integrated in Disaster Command Centres for visualisation and analysis of robot operators' activities in unmanned SAR scenarios. The result will be a well-developed e-learning methodology of self-paced study, accessible 24 hours a day.

In the ICARUS project several types of unmanned vehicles will be used, so from a training point of view the main objective is to deliver software tools that can simulate such a system. Different types of simulation (ground, air, water) will be developed and integrated to perform complex training of future ICARUS operators. The training tool will be capable of simulating predefined scenarios where virtual robots would send sensor data to the Command and Control Component operated by rescue services so that they can assess the simulated emergency and act accordingly. Furthermore, scenarios could be recorded from past events and then re-run for training purposes by using this tool.

The Command and Control Component for support rescue services will integrate all sources of spatial information such as maps of the affected area, satellite images and sensor data coming from the unmanned robots in order to provide a situation snapshot to the rescue team and thus facilitate decision-making. The interactive human-machine interface that uses semantic information to operate robots will be used for rescue operations. The Command and Control Component will equip rescue teams with ICARUS robots. Control decisions will be coordinated and supervised and therefore tasks will be executed with decreased risk.

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