The ICARUS Project - Command, Control and Intelligence (C2I)

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***Abstract*— This paper describes the features and concepts behind the Command, Control and Intelligence (C2I) system under development in the ICARUS project, which aims at improving crisis management with the use of unmanned search and rescue robotic appliances embedded and integrated into existing infrastructures. A beneficial C2I system should assist the search and rescue process by enhancing first responder situational awareness, decision making and crisis handling by designing intuitive user interfaces that convey detailed and extensive information about the crisis and its evolution. The different components of C2I, their architectural and functional aspects are described along with the robot platform used for development and field testing.**

I. Introduction

After the earthquakes in l'Aquila, Haiti and Japan, the European Commission acknowledged that there exists a large gap between robotic technologies developed for experimental use in laboratory conditions and their concrete counterparts deployed in the theater of Search and Rescue (SAR) operations and crisis management. There have been recent efforts [1] where C2I robots have been deployed for SAR, but the focus was mainly on human-robot cooperation and there is no holistic approach to enable control of heterogeneous robotic assets. The requirement for customized robots and their control centers, equipped to provide a comprehensive Common Operational Picture (COP) for SAR is being addressed by ICARUS.

In the scope of the ICARUS project [2, 3], SAR is defined as the search for (and provision of aid to) people who are in distress or imminent danger. ICARUS concentrates on the development of unmanned SAR technologies for detecting, locating and rescuing humans. Literature on research efforts towards the development of unmanned Search and Rescue tools exists, however this research effort stands in contrast to the practical reality in the field, where unmanned search and rescue tools experience major difficulties in finding their way towards end-user acceptance.

ICARUS addresses two main search and rescue situations: Urban SAR (USAR) and Maritime SAR (MSAR), as illustrated in Figure 1. Urban search-and-rescue in the context of ICARUS is synonymous with operations in human inhabited regions in the aftermath of natural or man-made disasters such as earthquakes and industrial accidents. MSAR encompasses disaster operations on marine surfaces like coastlines, rivers and seas, for example, the Costa Concordia disaster. ICARUS focuses on the development of specialized robotic systems for such applications.

(a) MSAR

(b) USAR

Figure 1. An artist's impression of ICARUS unmanned SAR operations.

The ICARUS project addresses these issues, with the aim of bridging the gap between the research community and end-users by developing a toolbox of integrated components for unmanned Search and Rescue. The ICARUS project development objectives are:

- Sensitive IR light sensors capable of human detection.
- Unmanned Aerial Vehicle (UAV), Unmanned Surface Vehicle (USV) and an Unmanned Ground Vehicle (UGV) with a robot arm manipulator controlled by an exoskeleton.
- Heterogeneous robot collaboration capabilities between unmanned SAR devices.
- A self-organizing cognitive wireless communication network, ensuring network interoperability.

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- A Command, Control and Intelligence (C2I) system and its integration with the human SAR teams (which is the our main focus - further addressed in section II).
- Training and support system of the unmanned SAR tools, for human SAR teams.

II. Command, Control and Intelligence (C2I) System

In a disaster struck area, the Local Emergency Management Authority (LEMA) is responsible for the overall command, coordination and management of the response operation. The C2I system will provide extensive interfaces to incorporate unmanned systems, for augmenting the capabilities of SAR operation planning and execution. The seamless integration of human SAR teams with unmanned platforms [4] is an integral feature of the C2I system.

Figure 2. C2I deployment and communication framework

The C2I system of ICARUS consists of a central Mission Planning and Coordination System (MPCS), field portable Robot Command and Control (RC2) sub-systems, a portable force feedback exoskeleton interface for robot arm tele-manipulation and field mobile devices. The deployment of C2I sub-systems with their communication links for unmanned SAR operations is shown in Figure 2.

A. *MPCS and RC2*

The MPCS is the nerve center for the unmanned SAR operations. Mission planning is the first task that is undertaken at the disaster site. The MPCS will assist SAR teams in disaster data analysis, area reduction, resource assessment and assignment, monitoring and coordinating actors and systems in the field, communications with stakeholders, and updating mission plans. Each rugged RC2 sub-system assigned to a particular sector of the disaster area is in charge of monitoring and where feasible or required, individual control of ICARUS robotic assets and communication with field response teams.

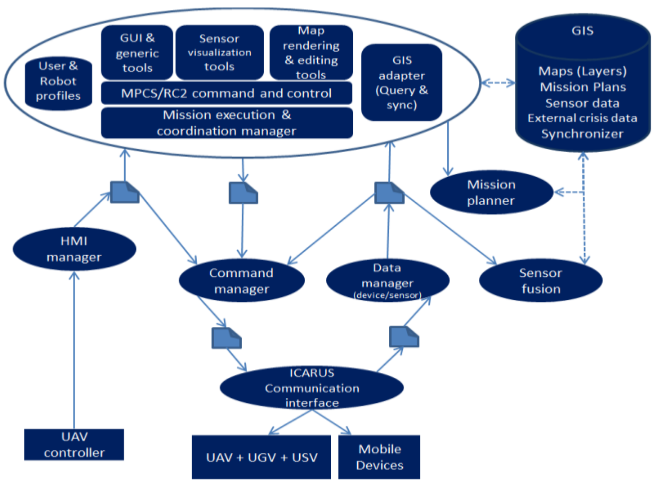

Figure 3. MPCS and RC2 components (nodes) based on ROS

The software architectures of the MPCS and RC2, shown in Figure 3, use the Robot Operating System (ROS) [5] as their middleware. The motivation behind the usage of a distributed framework like ROS is to maximize the reusability of available robot sensor visualizations, sensor fusion and control algorithms, and to adopt a standard framework used extensively on robotic platforms. This approach is coherent for rapid integration of the C2I with diverse robotic platforms in different deployment scenarios and provides a flexible approach in comparison with contemporary solutions. Existing robot command and control centers are either coupled to a specific robot platform or fixed to a specific SAR deployment scenario.

Geo-referenced base maps of the disaster area are initially loaded from a local Geographic Information System (GIS) repository relying on Open Street Maps (OSM) [6] and external crisis map providers such as GDACS [7] and MapAction [8]. The GIS schema is modeled on the Humanitarian Data Model (HDM) and is extended to include tags for representing robot profiles, geo-tagged sensor data and data mining capability.

The communication network will be specifically adapted to manage links between the MPCS, RC2, manned teams and unmanned systems. A communication handler uses local databases on all the deployed nodes to specify QoS for data flows, data measurements and dynamic selection of transport protocols for reconfiguring nodes within the network.

A data fusion node at the MPCS gathers an initial set of high altitude (and presumably low accuracy) images from an exploration by a high altitude fixed wing UAV. These images are stitched to create the initial map of the disaster area. In parallel, this map image is parsed by surface contextualization (characterization) that extracts concepts such as forests, water, buildings, roads etc. The RC2 operator will then ask for higher accuracy, lower altitude images on specific areas to update the map with visual images, possible location of victims, 3D structures and update the GIS with latest information. Data fusion is performed at the sector (RC2) level and at the global (MPCS) level, where all available information is eventually merged.

The mission execution and coordination manager at the MPCS has a symbolic planner that queries a specialized planner for computing robot path planning, best viewing positions, search area sectorization, deployment of assets etc. The specialized planner consists of a semantic environment constructor and query processor which gathers data from the GIS and data fusion feed to generate an interoperable mission plan for both SAR manned and unmanned systems.

The MPCS/RC2 user interface (Figure 4) renders the Common Operational Picture (COP). Map overlays from different sources provide an accurate representation of the disaster site. Robot sensor data such as 3D laser scans, 3D pose, GPS, power levels, network strength and live video streams can be visualized within the user interface. The user can command an automated mission planner to generate mission plans for allocating and scheduling tasks to robots and SAR personnel. The user can also modify mission plans through mission authoring interfaces to annotate maps using polygons to mark sectors, waypoints for robots navigation, text based instructions etc. The mission plan is relayed to each RC2 sub-system (in a sector) via the communication link.

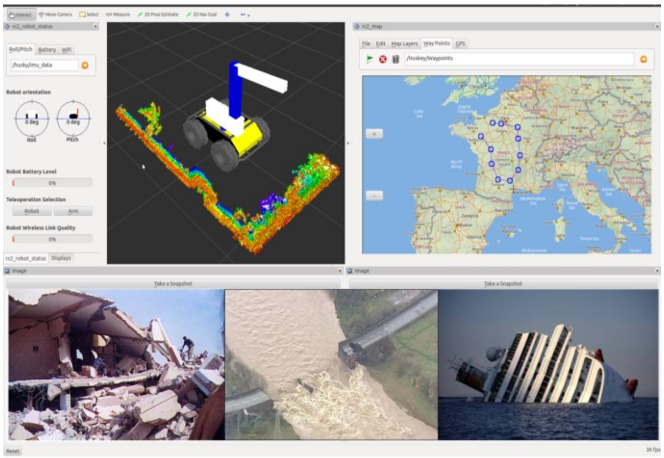

Figure 4. Early C2I mockup for land, air and sea scenarios

The mission plan generated and distributed by the MPCS is executed by the RC2 operator. The SAR task specific commands are relayed to robotic platforms (Figure 3) having sufficient autonomy to handle the request or to operators who act as supplementary controllers of particular robots (e.g. remote controlled UAV). Generic robot control interfaces (joysticks and 3D haptic interfaces) at this local base station enable field operators to control robots by analyzing their sensor data in real time. Data from robot sensors are visualized to get a local operational picture and to monitor the progress of the SAR mission. The automated mission coordination manager or the human operator will coordinate the actions between robots. The pending and completed goals of the mission will be highlighted on the user interface for effective task management.

The RC2 can be seen as a local base station for a specific sector, with handheld devices (developed in ICARUS) that connect with the RC2 to inform relevant events and information. Through these wearable interfaces, human personnel exchange text, voice, images or videos with the RC2.

B. *Force Feedback Exoskeleton*

A force feedback exoskeleton is an additional capability included in the ICARUS C2I, specifically developed to support teleoperation of a heavy duty robotic arm mounted on a large UGV under development in the project. Compared to standard rate control interfaces currently implemented on excavator manipulators, the purpose of the force-feedback exoskeleton is to provide a more intuitive control of the excavator motion and render contact information from the working environment. SAR applications include debris removal and feedback from mechanical tools and payloads deployed on the robotic arm. The interface is expected to improve operational efficiency, and safety of the SAR teams and victims, by adding additional signal like guidance forces related to operation path or range of motion limitations.

The ICARUS exoskeleton is based on the SAM exoskeleton [9, 10] developed previously (Figure 5) by a consortium led by Space Applications Services. SAM is an anthropomorphic 7 degrees of freedom wearable arm interface. The ICARUS version will be made sturdier, lighter and consist of an arm and hand interface. Each joint has position and torque sensors as well as a DC motor associated in series with a planetary gearbox and a capstan reducer.

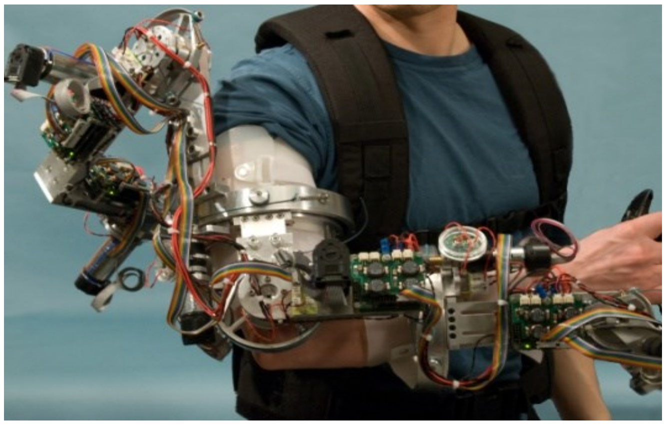

Figure 5. SAM 7dof force feedback arm exoskeleton

C. *Mobile Devices for First Responders*

In response to the desire of end-users for hand-held situational awareness tools, a unique mobile application enabling first responders to compliment the robotic operations is under development. This active map follows the movements of the responder using on-board sensors such as the GPS, digital compass and accelerometer. The application provides access to updated maps of the disaster area and renders information including locations of robots, team activities, victim locations, hazardous areas and other disaster data updates; which it receives from the RC2 system. Users can use the application's geo-tagged text, image and video note taking capabilities to capture otherwise inaccessible field information. Synchronization of this data with the MPCS and RC2 enables the entire SAR team including the first responder, robot operators and mission managers to make better decision making during the mission. Finally, communication features such as text and voice using the ICARUS communication infrastructure allows real-time interaction between first responders and RC2 operators. The deployment of the application takes advantage of the fact that many responders already carry a smartphone or tablet.

III. PRELIMINARY TEST TRIALS

While the paradigm adopted for the C2I supports an extensive range of heterogeneous platforms (ground, aerial and marine), the preliminary testing to support the design and evaluation of HMI components was conducted using a wheeled UGV platform.

A. *Test Robot Platform*

A Clearpath Husky A200 (Figure 6a) provided by Space Applications Services has been chosen as an appropriate test platform. The ruggedized platform provides locomotion capabilities in unstructured outdoor environments, has a significant payload capacity, enabling the testing of the C2I capabilities in harsh outdoor conditions. To test telemanipulation concepts and interfaces, the base platform is augmented with a manipulator controlled through a 3D haptic interface. A full sensor payload for the platform includes a Stereo Camera, Laser Range Finder (LRF) mounted on a pan-tilt unit, GPS, Inertial Measurement Unit (IMU) and a PTZ camera.

(a) Husky A200 platform (b) Field campaign site

Figure 6. Robot test platform and demonstration site

At this preliminary testing, a simple system architecture has been adopted whereby the RC2 and other operator devices are connected via LAN to each other using an outdoor WiFi access point. The mobile robot connects to the access point, allowing command and control from the RC2. Additionally, the mobile robot is capable of variable onboard autonomy ranging from simple obstacle avoidance through waypoint navigation to basic frontier exploration in indoor environments.

B. *C2I Prototype*

A prototype of the RC2 was realized by developing plugins for the rviz-ROS visualization interface.

- A global map plugin displays OSM, Google and Yahoo base maps. It provides tools for the operator to sectorize an area and add waypoints that are published to the robot as a mission plan.
- A robot sensor visualization plugins displays the 3D pose of the robot, battery level, network quality and options to change controller modes.
- A 3D model of the robot was rendered relative to the point clouds from the LRF scans to assist the operator for robot during teleoperation.

C. *Early Field Campaign*

An initial field campaign was executed in a quarry at Haut-le-Wastia in Belgium (Figure 6b). The primary purpose of the field trial was to test the operational setup of the test system as well as collect preliminary data sets that would speed up the development and evaluation of data specific C2I components for the RC2. The RC2 prototype was used for mobile manipulation, exploration and reconnaissance scenarios, defined in the EURATHLON competition [11]. The robot operator was successful in controlling the robot in a smoke filled tunnel (Figure 7), a cave and manipulating valves on a fire fighting platform (Figure 6a) using the C2I interface. Waypoints on the map (Figure 7) were used in the outdoor navigation scenario, shown in Figure 6b.

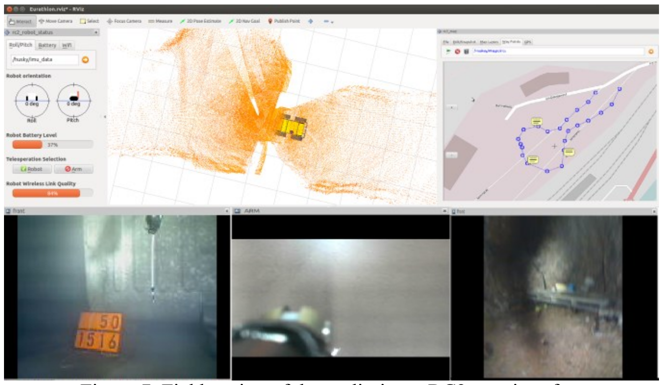

Figure 7. Field testing of the preliminary RC2 user interface

CONCLUSION

The C2I system of the ICARUS project is an essential set of hardware and software components, instrumental in providing interfaces for SAR responders to get a common operation picture for supervising SAR tasks. The MPCS, RC2, Exoskeleton and mobile field devices of the C2I system provides a distributed capability for planning and controlling unmanned robots and SAR personnel, thus improving the effectiveness of the response to crisis situations. The flexibility of integrating the C2I system with diverse robotic platforms will enable a large variety of robots to be tested, evaluated and eventually used in SAR operations.

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REFERENCES

[1] Natural Human-Robot Cooperation in Dynamic Environments (NIfTi), EU FP7, Cognitive Systems & Robotics (http://www.nifti.eu/)

[2] G. De Cubber, D. Doroftei, Y. Baudoin, D. Serrano, K. Chintamani, R. Sabino, S. Ourevitch, "ICARUS: An EU-FP7 project Providing Unmanned Search and Rescue Tools", IROS2012 Workshop on Robots and Sensors integration in future rescue INformation system (ROSIN'12), October 11th, 2012

[3] G. De Cubber, D. Doroftei, Y. Baudoin, D. Serrano, K. Chintamani, R. Sabino, S. Ourevitch, "ICARUS: Providing Unmanned Search and Rescue Tools", 6th IARP Workshop on Risky Interventions and Environmental Surveillance (RISE), Warsaw, Poland, September 2012

[4] D. Doroftei, G. De Cubber, K. Chintamani, "Towards collaborative human and robotic rescue workers", 5th International Workshop on Human-Friendly Robotics (HFR2012), October 18th-19th, 2012.

[5] Robot Operating System (http://www.ros.org/wiki/)

[6] Open Street Maps (http://www.openstreetmap.org/)

[7] Global Disaster Alert & Coordination System. (http://www.gdacs.org/)

[8] MapAction (http://www.mapaction.org/)

[9] P. Letier, E. Motard, J.P. Verschueren and A. Preumont, EXOSTATION : Haptic Exoskeleton Based Control Station, In Proc of the IEEE 2010 International Conference on Robotics and Automation, May 3-8 2010, Anchorage, Alaska.

[10] P. Letier, E. Motard, M. Ilzkovitz, A. Preumont, J.P. Verschueren. SAM: Portable haptic arm exoskeleton upgrade technologies and new applications fields. In proc. of the 11th ESA Workshop on Advanced Space Technologies for Robotics and Automation, Noordwijk, April 2011.

[11] EURATHLON 2013, robot competition supported by the European Commission FP7, 23-27th September 2013, at Berchtesgaden, Germany (http://www.eurathlon2013.eu/eurathlon_2013.html)