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SEARCH AND RESCUE ROBOTS DEVELOPED BY THE EUROPEAN ICARUS PROJECT

Abstract

This paper discusses the efforts of the European ICARUS project towards the development of unmanned search and rescue (SAR) robots. ICARUS project proposes to equip first responders with a comprehensive and integrated set of remotely operated SAR tools, to increase the situational awareness of human crisis managers. 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, which is a complex and dangerous task. The introduction of remotely operated SAR devices can offer a valuable tool to save human lives and to speed up the SAR process. Therefore, ICARUS concentrates on the development of unmanned SAR technologies for detecting, locating and rescuing humans. The remotely operated SAR devices are foreseen to be the first explorers of the area, along with in-situ supporters to act as safeguards to human personnel. While the ICARUS project also considers the development of marine and aerial robots, this paper will mostly concentrate on the development of the unmanned ground vehicles (UGVs) for SAR. Two main UGV platforms are being developed within the context of the project: a large UGV including a powerful arm for manipulation, which is able to make structural changes in disaster scenarios. The large UGV also serves as a base platform for a small UGV (and possibly also a UAV), which is used for entering small enclosures, while searching for human survivors. In order not to increase the cognitive load of the human crisis managers, the SAR robots will be designed to navigate individually or cooperatively and to follow high-level instructions from the base station, being able to navigate in an autonomous and semi-autonomous manner. The robots connect to the base station and to each other using a wireless self-organizing cognitive network of mobile communication nodes which adapts to the terrain. The SAR robots 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.

1. Introduction

1.1 Search and Rescue and Project Context

The general field of search and rescue includes many specialty sub-fields, mostly based upon terrain considerations. ICARUS [1] will mainly focus on two types of search and rescue (SAR): Urban Search and Rescue and Maritime Search and Rescue and this paper will focus on the efforts on the urban SAR side.

Urban SAR is considered a multi-hazard discipline, as it may be needed for a variety of hazards including earthquakes, cyclones, storms and tornadoes, floods, dam failures, technological accidents, terrorist activities, and hazardous materials releases. Urban search and rescue involves the location, extrication, and initial medical stabilization of victims trapped in confined spaces due to natural disasters, structural collapse, transportation accidents, mines and collapsed trenches. USAR teams in different countries may be organized in a variety of ways, but they are often associated with firefighting services.

The increasingly complex methods and procedures, and the modern ability to bring in teams from far afield has brought a very strong drive for standardization within nations and internationally, most obvious in the role of the UN’s International Search and Rescue Advisory Group (INSARAG) in large natural disasters.

In science and research, there is a vast literature on research efforts towards the development of unmanned Search and Rescue tools. However, 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.

In this context, the European Commission’s Directorate-General for Enterprise and Industry decided to fund ICARUS [2], a Research project (global budget: 17.5M€) which aims to develop robotic tools which can assist “human” crisis intervention teams.

The overall purpose of the ICARUS project is to apply its innovations for improving the management of a crisis and by doing so to reduce the risk and impact of the crisis on citizens. The use of unmanned search and rescue devices embedded in an appropriate information architecture and integrated into existing infrastructures will help crisis personnel by providing detailed and easy to understand information about the situation. The proposed system will inform crisis personnel about real dangers present on the ground, and will thus increase their performance in resolving the situation.

1.2 ICARUS Unmanned Ground Vehicles

The Belgian First Aid and Support Team (B-FAST) 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 development of the aforementioned types of robotic systems, using existing base platforms.

The use of such (semi-)autonomous ground vehicles for search and rescue applications offers several advantages. Instead of sending first responders directly to the potentially hazardous site of a disaster, unmanned vehicles can explore the area and collect valuable information (e.g. about the location of victims) without risking rescuers’ lives. Furthermore, vehicles equipped with sophisticated sensor systems could detect hazards earlier and much more reliably than humans could. By combining the capabilities of an experienced rescuer who remotely operates a large UGV with the vehicle’s autonomy, a powerful system is created that can deal with a large variety of dangers. Such a combination is in the field of search and rescue. Instead of having only one UGV, the ICARUS project aims at using a team consisting of a large and a small UGV. The large one will serve as base platform that can cover long distances at comparably shorter times and surmount even large obstacles. Thus, a small vehicle can be brought very quickly close to the potential location of victims. Thanks to its small size and weight, it can be used to explore narrow spaces (e.g. between the debris of a collapsed building) without injuring people or causing further damage to structures. The large UGV will also serve as a base platform for unmanned air vehicles. This helps to explore large areas easier and in a much shorter time. The powerful manipulator attached to the large UGV can be used by a tele-operator to remove large obstacles that would block the vehicle’s path. Thus, the operator’s tele-presence is not limited to getting sensor information or small-scale manipulation like in usual approaches, but is extended to the movement of large objects. The proposed use of an intuitive user interface using an exoskeleton with integrated force feedback will allow easy tele-control of the manipulator.

2. Large Unmanned Ground Vehicle for Search & Rescue Operations

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 are envisaged:

- Mobile sensor platform. Gathering a large amount of precise data is necessary for (semi-)autonomous navigation in challenging environments 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 (shown in Figure 1) 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 a time-of-flight camera for terrain traversability analysis [3,4]. Victim detection sensors will be mounted on the platform. The manipulator will be designed as a 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 LUGV will be a semi-autonomous platform, providing various degrees of autonomy. In order to achieve this, a behaviour-based control framework will be embedded [5-8] which enable to fuse multiple sensor inputs [9] in a coherent framework, enabling real-time performance and cognitive reasoning while keeping the human operator in the loop. The autonomous navigation capabilities embedded on this robotic system stem from previous research efforts on different projects [10] and different robot systems [11] and are ported to this system in the framework of this integration project.

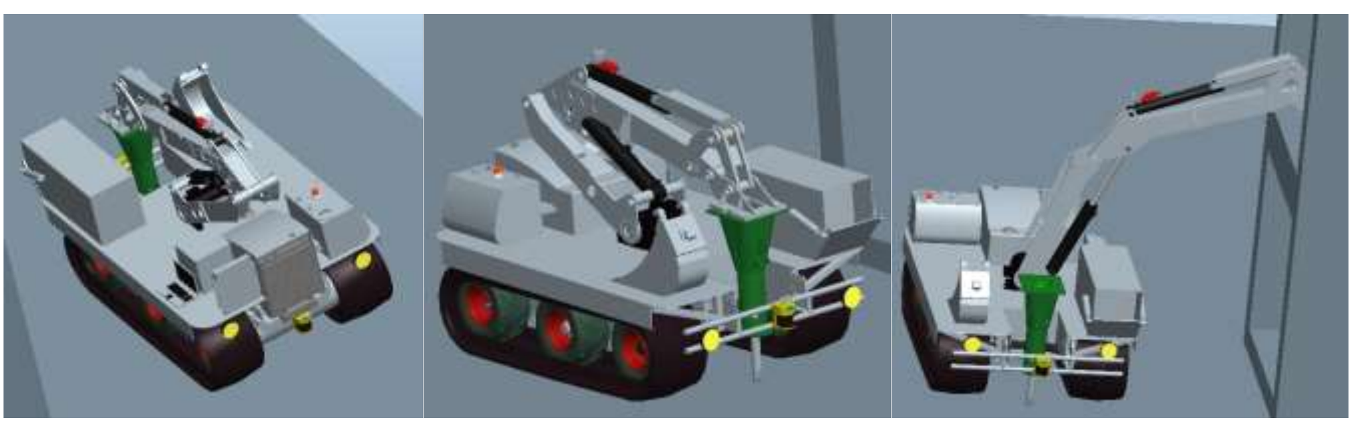

Figure 1: Large Unmanned Ground Vehicle

3. Small Unmanned Ground Vehicle for Search & Rescue Operations

The Small UGV (SUGV) consists of a Digital Vanguard robot [12] by Allen Vanguard, as shown in Figure 2. This robotic system 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 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.

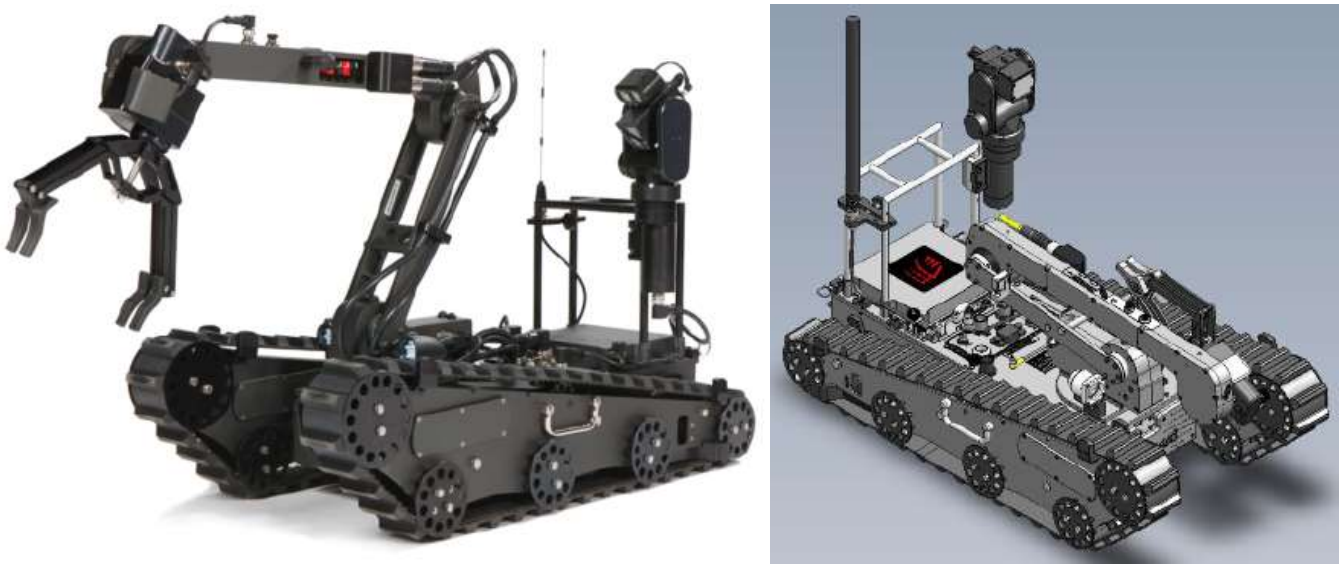

Figure 2: Small Unmanned Ground Vehicle

4. Integrated demonstration of unmanned rescue tools

The performance of these systems will be validated using scenarios in which the LUGV and the SUGV will be used in a combined manner. At a demonstration site, the vehicles will fulfil several exploration tasks during which all of their subsystems will have to demonstrate that they meet the requirements.

The demonstration scenario will consist of an earthquake similar to the one in L'Aquila or Haiti, which has devastated a large area of a mixed urban and rural region. An integrated team of ICARUS UASs and UGVs will join the human crisis managers of the Belgian First Aid and Support Team, working in close collaboration to find human survivors as early as possible. This demonstration scenario will be executed on the Belgian military base of Marche-en-Famenne, which is used by B-FAST and other international first aid and support teams as a training area.

Within the military base of Marche-en-Famenne, there is an abandoned village (Focagne, see Figure 4), which will be used as an area to focus the search and rescue activities on. ICARUS unmanned tools (ground robots and aerial robots) will survey this area and search for victims (see Figure 3).

Initial validation tests of individual platforms are foreseen in 2014, whereas the full-scale integrated ICARUS demonstration (including multiple UAS and unmanned ground vehicles collaborating with B-FAST personnel) is planned to be executed in summer 2015.

Figure 3: Artist's impression of the ICARUS land demonstration

Figure 4: Pictures of the test and validation site: skeleton house for indoor operations and rubble field for outdoor mobility operations

5. Conclusions

Currently, there are only few systems that are able to navigate fully or at least semi-autonomously in rough highly unstructured environments. Most of the existing vehicles are only research platforms that are not well-suited for the use in search and rescue applications. In contrast, the approach followed in the ICARUS project targets using (semi-)autonomous systems in disaster areas. A further novel aspect is the combination of two very different UGVs – a larger and a smaller one. Using heterogeneous teams yields the ability to cover huge distances in a reasonable amount of time, while still being able to explore areas where there is not much space to manoeuvre. Many approaches in the field of robotics offer only two control modes from which the operator can choose: Either the vehicle is controlled completely by a tele-operator, or it is fully autonomous. There is often nothing in between, no option to only exercise partial control over the vehicle. The control system of the UGV developed in the ICARUS project, by contrast, shall allow for a sophisticated interaction between operator and vehicle where each of the two can assist the other. Manipulators used in the field are usually rather small and only allow for manipulating light-weight objects. The robotic arm that will be mounted on the large UGV will be much more powerful. Being able to move objects with a weight of up to 250kg yields a completely new type of tele-presence: The operator will even be able to move obstacles that block the path of the vehicle. As such, it can be concluded that the ICARUS project proposes novel solutions in the field of unmanned ground vehicles for search and rescue operations.

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References

[1] Yvan Baudoin, Geert De Cubber, *TIRAMISU-ICARUS: FP7-Projects - Challenges for Robotics Systems*, IARP RISE - Robotics for Risky Environment - Extreme Robotics, 2013

[2] Geert De Cubber, Daniela Doroftei, Daniel Serrano, Keshav Chintamani, Rui Sabino, Stephane Ourevitch, *The EU-ICARUS project: developing assistive robotic tools for search and rescue operations*, IEEE International Workshop on Safety, Security & Rescue Robotics (SSRR), 2013

[3] Haris Balta, Geert De Cubber, Daniela Doroftei, Yvan Baudoin, Hichem Sahli, *Terrain Traversability Analysis for off –road robots using Time-Of - Flight 3D Sensing*, IARP RISE - Robotics for Risky Environment - Extreme Robotics, 2013

[4] Geert De Cubber, Daniela Doroftei, Hichem Sahli, Yvan Baudoin, *Outdoor Terrain Traversability Analysis for Robot Navigation using a Time-Of-Flight Camera*, RGB-D Workshop on 3D Perception in Robotics, 2011

[5] Christopher Armbrust, Martin Proetzsch, Karsten Berns, *Behaviour-Based Off-Road Robot Navigation*, KI - Künstliche Intelligenz - Springer Berlin / Heidelberg, pp. 155-160, May 2011

[6] Bernd-Helge Schäfer, Christopher Armbrust, Tobias Föhst, Karsten Berns, *The Application of Design Schemata in Off-Road Robotics*, IEEE Intelligent Transportation Systems Magazine, pp. 4-27 , Spring 2013

[7] Daniela Doroftei, Geert De Cubber, Eric Colon, Yvan Baudoin, *Behavior based control for an outdoor crisis management robot*, Proceedings of the IARP International Workshop on Robotics for Risky Interventions and Environmental Surveillance, pp. 12-14, 2009

[8] Daniela Doroftei, Eric Colon, Geert De Cubber, *A behaviour-based control and software architecture for the visually guided Robudem outdoor mobile robot*, Journal of Automation, Mobile Robotics & Intelligent Systems, 2(4), 2008

[9] Geert De Cubber, Daniela Doroftei, *Multimodal terrain analysis for an all-terrain crisis Management Robot*, IARP HUDEM Workshop, 2011

[10] Yvan Baudoin, Daniela Doroftei, Geert De Cubber, Sid Ahmed Berrabah, Carlos Pinzon, Fabrice Warlet, Jeremi Gancet, Elvina Motard, Michel Ilzkovitz, Lazaros Nalpantidis, *View-finder: robotics assistance to fire-fighting services and crisis management*, IEEE International Workshop on Safety, Security & Rescue Robotics (SSRR), pp. 1-6, 2009

[11] Christopher Armbrust, Tim Braun, Tobias Föhst, Martin Proetzsch, Alexander Renner, Bernd-Helge Schäfer, Karsten Berns, RAVON- The Robust Autonomous Vehicle for Off-road Navigation, Woodhead Publishing Limited - Using robots in hazardous environments: Landmine detection, de-mining and other applications, 2010

[12] Allen Vanguard, *Remotely Operated Vehicle - Digital Vanguard*, Datasheet, 2012