Chapter 1

Introduction to the Use of Robotic Tools for Search and Rescue

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Additional information is available at the end of the chapter

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Abstract

Modern search and rescue workers are equipped with a powerful toolkit to address natural and man-made disasters. This introductory chapter explains how a new tool can be added to this toolkit: robots. The use of robotic assets in search and rescue operations is explained and an overview is given of the worldwide efforts to incorporate robotic tools in search and rescue operations. Furthermore, the European Union ICARUS project on this subject is introduced. 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. 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 command and control 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.

Keywords: robotics, search and rescue, crisis management, disaster management

1. Introduction: Why do we need search and rescue robots?

Recent dramatic events such as the earthquakes in Nepal and Tohoku, typhoon Haiyan or the many floods in Europe have shown that local civil authorities and emergency services have difficulties in adequately managing crises. The result is that these crises lead to major disruption of the whole local society. On top of the cost in human lives, these crises also result in financial consequences, which are often extremely difficult to overcome by the affected countries.

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 (SAR) devices can offer a valuable tool to save human lives and to speed up the search and rescue process.

Indeed, more and more robotic tools are now leaving the protected lab environment and are being deployed and integrated in the everyday life of citizens. Notable examples are automated production plants in industry, but also the widespread use of consumer drones and the rise of autonomous cars in public space. Also in the world of search and rescue, these robotic tools can play a valuable role.

Of course, this does not mean that the introduction of robotic tools in the world of search and rescue is straightforward. On the contrary, the search and rescue context is extremely technology unfriendly, as robust solutions are required which can be deployed extremely quickly. Chapter 2 of the book will give a more in-depth review of the requirements for search and rescue robotics, as proposed by the human users of these systems. Indeed, one crucial aspect must not be forgotten: the robotic tools must not have the objective to eliminate the need of human search and rescue workers! Instead, these robotic assets must be seen as yet another tool in the ample toolkit of human search and rescue workers in order to allow them to do their job better, faster, and safer. In the following paragraphs, each of these statements is further developed.

1.1. Better

As stated before, robotic search and rescue tools are there to assist human rescue workers. One of their main strong points is that they can increase the situational awareness of the relief workers by giving them a better and higher quality view on the nature of the crisis. Indeed, robotic tools are able to give better insights by looking at disaster scenes from a point of view which is nearly impossible (or impractical or very unsafe) to obtain by humans. One example is the use of drones which can provide a quick birds-eye view of a disaster scene, which is crucial information for the planning of rescue operations. Another example is the use of underwater robots for mapping debris or searching for human remains under the water, which is an essential recovery operation after floods, tsunamis, or typhoons have damaged and blocked ports and waterways.

The miniaturization of sensing technology has led to the result that search and rescue robots can pack more and more sophisticated sensors (high-definition video cameras, thermal cameras, 2D and 3D laser range finders, sensors for measuring chemical, biological, and radiological contamination, …), allowing for precise and fast cartography. Undisturbed by

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cloud cover, these robotic assets are therefore becoming a very good complimentary tool to space-based remote sensing, which remains essential to cover large areas. The introduction of these advanced sensors on unmanned search and rescue robots opens the possibility to perform damage assessment operations with these unmanned assets, thereby keeping the human operators safe. Nowadays, unmanned systems are capable of producing accurate three-dimensional (3D) maps of the environment, pinpointing objects of interest (human survivors, but also potential dangers like fire hazards or chemical spills) in these 3D models. Such maps provide highly valuable information to human search and rescue workers in the assessment phase, where they need to decide which buildings/structures to enter first. These 3D maps also help for cartography of the debris after the crisis, which can be of help to coordinate the recovery operations and the structured removal of debris. Advances in telecommunication technology now also make it possible to let remote experts (possibly at the other side of the world) analyze damage to structures, based on live high-quality data gathered by unmanned systems. Such remote expert analysis can be invaluable to assess the structural integrity of buildings or shipwrecks.

Unmanned assets equipped with powerful sensors have an important role to play as data gatherers during a crisis, not only to support the immediate relief operations. Indeed, in the aftermath of a crisis, often a legal battle entails between people suffering from damages, the authorities, and insurance companies. Accurate, time-stamped and geo-referenced data collected by unmanned systems during the crisis can serve as evidence to settle these disputes. An example of this happening in practice is the detection by ad drone of illegal man-made dyke breaches during the 2014 floods in Bosnia-Herzegovina [1] (more information: see chapter 10).

Using unmanned assets can also have more sense from an economical point of view. Indeed, typical search and rescue operations at land or sea happen via the deployment of manned rescue helicopters and/or patrol boats, both costing thousands of dollars an hour to operate. Unmanned assets can drastically bring this operational cost down and free up the manned assets for high-priority tasks.

1.2. Faster

In a search and rescue context, time is a critical parameter, as the chance of survival of victims decreases quickly. It is therefore essential to deploy all the search and rescue assets as quickly as possible. However, during a large crisis, it is often the case that traditional search and rescue assets (rescue helicopters, rescue boats, …) are extremely overloaded, e.g., for evacuating victims. The fast deployment of ubiquitously present unmanned rescue tools can greatly speed up the rescue operations.

A main benefit of mostly the aerial unmanned tools is that they enable human rescue workers to very quickly obtain a global overview of the situation and the dangers in the crisis area. The result is that the search and rescue workers can thus plan their operations faster, not having to wait until satellite imagery is available or a ground-based survey is performed.

1.3. Safer

An obvious advantage of using robotic systems in comparison to their manned counterparts is that the unmanned systems keep the human rescue workers out of harm. This is especially important in earthquake response scenarios, where search and rescue workers now still have to enter semi-demolished structurally unstable buildings to search for survivors, terrified by the possibility of aftershocks bringing the whole structure down. Indoor drones and ground robots are specifically suited for these tasks.

Also crisis where there is a chemical, biological, or radiological component pose a huge problem for human relief workers, as proven by the dramatic events in Fukushima where a tsunami caused a meltdown of three nuclear reactor cores, exposing the environment to nuclear radiation. In such circumstances, robotic assets can be the only tools to correctly deal with the crisis, without endangering more human lives.

At sea, it is currently the case that rescue operations need to be halted at night or when the sea gets too rough, because it would be too dangerous for the human search and rescue workers. Robotic assets certainly do have difficulties as well with rough environmental conditions like night-time operation, heavy wind, rain or rough sea state, but in a risk-assessment context, it would be logical to deploy these unmanned systems instead of manned assets for risky operations. Furthermore, unmanned rescue tools show great promise for operations of victim search at sea during the night because it is easier to detect humans in the water than during the day (due to the larger thermal gradient between the human and the water) and the limited number of operations at night.

2. Search and rescue robotics efforts around the world

2.1. Internationally

From an operational side, the international urban search and rescue (USAR) community is organized via the INSARAG network [2], which falls under the United Nations umbrella. INSARAG establishes minimum international standards for USAR teams and methodologies for international coordination crisis response scenarios, based on the INSARAG Guidelines [3]. Via the elaboration of these standards, INSARAG drives technological development. The use of unmanned assets for crisis management has been acknowledged by the INSARAG group [4] and is one of the discussion points for the elaboration of future collaboration and coordination standards, in order to allow multi-national teams working in the same crisis area to share data from their unmanned assets. The International Maritime Rescue Federation [5] is taking up a similar—be it less globally coordinated—role in the world of marine search and rescue.

Support to operational deployment of robotic tools for search and rescue is given by initiatives as UAViators [6] and the Roboticists Without Borders program [7], where the former focuses on the use of aerial robotic tools (unmanned aerial vehicles or UAVs or drones) and the latter considers the use of all kinds of robotic tools (including marine and ground robots).

The objectives of the UAViators intiative are [8] to establish standards for the responsible use of UAVs and provide up-to-date regulatory information; document lessons learned and best practices; provide hands-on UAV training; inform UAV deployments after disasters; and catalyze research and information sharing. When a disaster strikes, the UAViators crisis map [8] is updated and UAV rescue teams can announce their capabilities and deployment details. The deployed UAV teams can then post data collected by their unmanned assets on this website, such that remote users, acting as digital humanitarians [9], can analyze the data. This approach of trying to organize and structure the relief operations with UAVs has led to some good results in the past, as can be read in a report [10] by FSD, CartONG and the Zoi Environment Network on the use of drones in humanitarian crises. As part of that report, they have created 14 success stories of the use of UAVs in crisis response, many of them with the help of people from the UAViators network.

The Roboticists Without Borders program [7] is an initiative by the Center for Robot-Assisted Search and Rescue (CRASAR) at Texas A&M University. It aims to create pools of professionals in ground, aerial, or marine robots or emergency response who are trained in disaster response and how to work with incident management, what are the types of missions and best match of systems with the needed data, and have participated in high-fidelity exercises. More geared toward the professional robotics community than the UAViators initiative, the Roboticists Without Borders program aims to find the right matches between universities, industry, and private individuals in order to deploy the right robotic systems to a particular incident, while at the same time gaining deeper insights into the needs and requirements of the disaster response community. CRASAR director Robin Murphy, founder of the Roboticists Without Borders program, has written an excellent book [11] on the subject of disaster robotics which describes different successful real-life deployments of this initiative (and others), including the scientific progress in the field.

From a scientific point of view, the international research direction in the field of Safety, Security, and Rescue Robotics is driven by a specific technical committee on this subject domain, launched by the Robotics and Autonomous Systems Group of the Institute of Electrical and Electronics Engineers. This technical committee was founded shortly after the first robots were deployed to help with the search operations during the 9/11 World Trade Center collapse, leading to an accelerated adoption of robots for homeland security and public safety. The primary activity for the committee is to engage emergency responders, federal and local government agencies, and non-governmental organizations for training and acquisition guidance.

Prototypes of robotic tools for search and rescue, developed in different laboratories worldwide, compete since 2001 annually with one another in the RoboCup Rescue competition [12]. This event—which falls under the umbrella of the RoboCup annual international robotics competition [13]—was inspired by the Kobe earthquake and pits robots to compete to find victims in a simulated earthquake environment. The robots have to operate totally autonomously and can score points by detecting victims and hazards and by mapping the environment. The aim of the competition is to encourage the transfer of academic research into the disaster-rescue domain, and to encourage research in a socially significant real-world domain, by offering a publicly appealing challenge [12].

2.2. United States of America

From 2012 to 2015, the US Defense Advanced Research Projects Agency (DARPA) has tried to increase the research and take-up of disaster response robotics by organizing a competition [14] where semi-autonomous robots had to execute a number of tasks in urban search and rescue disaster response scenarios. In order to end up with modular and versatile systems, these tasks were chosen very diverse and based upon present-day tasks executed by human search and rescue workers. Examples of tasks were driving with a vehicle, opening a door and entering a building, locating and closing a valve, and climbing a ladder [15]. The definition of the tasks led to the widespread use of humanoid-like robots in this event. The qualification to the event was dominated by the SHAFT robot by Google, which later withdrew from the challenge due to the military origins of the event. The competition was eventually won [16] by the Korean KAIST team with their humanoid HUBO robot, which managed to complete all tasks.

The US National Institute of Standards and Technology (NIST) plays an important role in the development of standardized test methodologies for search and rescue robotics [17]. Evolved from standardized test methodologies helping (primarily military) contractors validate and compare explosive ordnance disposal robots, NIST has developed specific test methodologies and standardized procedures for qualitatively and quantitatively evaluating the performance of search and rescue robotics. These NIST standardized test methodologies apply mostly to smaller ground robots, but are now also being extended to aerial robots and larger systems. The existence of standardized validation methodologies for search and rescue robotics is essential not only for scientists and developers to accurately compare multiple novel developments, but also for procuring agencies to choose the right robotic assets according to their specific needs.

Arguably, the institution contributing most to the introduction of robotic tools in the world of search and rescue is the aforementioned the Center for Robot-Assisted Search and Rescue (CRASAR) of the Texas A&M University [7]. CRASAR has as an objective to improve the crisis response lifecycle, by the introduction of robotic tools in the process. CRASAR members were among the first to deploy robotic tools for disaster management during the 9/11 attacks in 2001 and have since been actively involved in more than 15 documented deployments of disaster robots throughout the world, ranging from land to sea and air robots [11]. Associated to CRASAR is the Texas A&M Engineering Extension Service Disaster City testing grounds, featuring a training facility where human operators can learn to work with disaster management robots and where these robotic assets can be validated and compared to one another (e.g., following the NIST standardized test methodologies).

2.3. Far East

Located in a very disaster-prone area, countries like Japan, Korea, China and ASEAN member states have invested many resources in the development of novel disaster management tools, including robotic tools. These robotic tools were also put to use after the 2011 Great Eastern Japan Earthquake in Tohoku, Japan, where robotic assets, both from Japan as from the USA, were deployed to help in the disaster management operations [11, 18]. Ground and aerial robots helped for monitoring and surveillance operations, whereas marine robots assisted with clearing the harbors.

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Following up on this disaster, prof. Tadokoro of the Tohoku University organized during the 2015 UN World Conference on Disaster Risk Reduction in Sendai, Japan, a public forum on the Social Implementation of Disaster Robots and Systems [19]. During this event, lessons learnt from past deployments of disaster robotics tools were discussed and remaining bottlenecks were identified. One of the conclusions was that the present-day generation of robotic tools for disaster management still often lack robustness to operate in the tough environments encountered in crisis management. Therefore, the Japanese government started a Tough Robotics Challenge research and development project [20] in the framework of the Impact program. Looking into the future, the Japanese efforts toward the development of search and rescue robotics are going to be driven by the on-going need of the use of robotics for the clean-up and dismantling of the four reactors of the Daiichi nuclear power plant damaged in the Fukushima accident and by the prospect of the "Robot Olympics" which will be organized next to the Summer Olympics in Tokyo in 2020.

Reports of robotic search and rescue tools deployed in China less frequently reach international coverage, but there are some important successes to be reported. Already in 2013, the Chinese International Search and Rescue Team was supported by an unmanned aerial vehicle of the State Key Robotics Lab at Shenyang Institute of Automation to help with the relief operations after the Lushan earthquake [21]. As a very fine example of how novel technologies are brought from the lab directly into the field, the unmanned system performed real-time feature detection of disaster damage from live aerial video footage, thereby speeding up the classification of the damages on the terrain.

In the aftermath of the DARPA challenge, won by the Korean KAIST team as reported before, South Korea and the United States have agreed to start a joint research project [22] aimed at developing the next generation of robotics system for disaster environments.

2.4. Middle East and Russia

Confronted with a huge and often very inaccessible territory to cover by the emergency services, the Russian Federation is also investing in search and rescue robots. The focus in Russia is more on developing systems which are able to deal with extreme environments and environmental conditions. Examples are operation in Siberian and Arctic temperatures [23], mobility in swampy forests (taiga), polluted (nuclear) infrastructure, wide area search operations, etc. Compared to other countries in the world, research efforts are therefore more concentrated on developing larger, robust systems [24] with advanced mobility features and autonomous terrain traversability analysis capabilities and on validating these technologies on the terrain [25].

The major increase of their wealth has motivated Gulf State nations like Qatar and the United Arab Emirates (UAE) to invest in humanitarian activities, including the deployment and sponsorship of search and rescue robotics activities. The UAE Search and Rescue team was one of the first official state-run rescue teams in the world to be equipped with unmanned aerial systems. These are used domestically by response forces, but have also been used by the deployed UAE SAR team during the relief operations after the 2015 earthquake in Nepal to assess the condition of damaged buildings [26]. Next to this operational deployment of rescue robot tools, the UAE has also been sponsoring research in the field through the organizations of challenges and competitions. In 2015, the UAE organized the first "Drones For Good" international competition [27], which encourages positive applications of drone technology. The first edition of this annual competition was won by a Swiss search-and-rescue drone [28]. Acting as a follow-up of the DARPA challenge, the UAE has launched the Mohamed Bin Zayed International Robotics Challenge (MBZIRC) [29]. This is an international robotics competition, to be held every 2 years with total prize and team sponsorship of USD 5 Million. The first edition is scheduled to take place in 2017. Like in the DARPA challenge, teams will have to complete different tasks, but unlike the DARPA challenge, these tasks are more geared toward collaboration between aerial and ground robots, which will likely steer the developed solutions away from humanoid systems as those used during the DARPA challenge.

2.5. Europe

From an operational side, the European Union Civil Protection Mechanism (EUCPM) is since 2001 fostering cooperation and innovation among national civil protection authorities across Europe. The EUCPM currently includes all 28 European Union member states in addition to Iceland, Montenegro, Norway, Serbia, the former Yugoslav Republic of Macedonia and Turkey. Following the modalities of the EUCPM, member states can request and offer disaster response capabilities (e.g., water pumping capacity for flood relief). Motivated by driving the innovation in disaster management, the European Union Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG-ECHO) is now leading an effort to include the use of robotic tools, focused specifically on unmanned aerial systems, in the EUCPM framework. To this extent, an outdoor demonstration showcasing the benefits of unmanned systems for disaster relief operations was organized in the framework of the 2015 EU Civil Protection Forum [30, 31]. In the wake of this event, DG-ECHO organized a workshop for experts from participating states of the Union Civil Protection Mechanism (UCPM) to discuss the main challenges for the use of unmanned aerial systems in disaster management, in particular their deployment in the context of the EUCPM [32]. The workshop tackled the regulatory, operational, and strategic dimension of the use of unmanned aerial systems for disaster management.

European crisis management agencies have also taken it up to themselves to explore the use of robotic assets, specifically unmanned aerial systems, for managing response operations. They were supported in these efforts by the European Emergency Number Association, which set up a special working group on the topic of "drones," producing an operations manual [33] for emergency services, providing crisis responders a road book on how to best put unmanned aerial systems into operational service.

The operational efforts of the European Union to introduce rescue robots in the field are supported by decades of EU-sponsored research in this domain to develop robotic solutions which can make a difference on the field. One of the larger EU projects on this topic is the ICARUS project, which is the main subject of this book and which is briefly introduced in the next section. First, the following paragraphs discuss some other EU projects which have advanced the scientific research level in the use of robotic tools in each of the different levels (preparedness, response, and recovery) of the disaster management life cycle:

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- The ViewFinder project (2006–2009) [34] focused on the assessment phase, developing ground robotic agents operating in chemically contaminated disaster areas to establish whether the ground can be entered safely by human beings.
- The NIFTI project (2010–2013) [35] concentrated on developing methodologies to let humans and ground robots collaborate better, by developing novel human-robot interaction modalities for urban search and rescue robots. A noteworthy achievement of the NIFTI team was a real-life human-robot team deployment in an earthquake area after the 2012 earthquake in Emilia-Romagna region in Northern Italy. Multiple ground and aerial robotic tools were used in order to assess the damage done to several church buildings.
- The AIRBEAM project (2012–2015) [36] developed a situational awareness toolbox for the management of data coming from unmanned aerial systems and space-based assets in the cases of disasters.
- The DARIUS project (2012–2015) [37] focused on reaching effective levels of interoperability such that unmanned systems can be shared between several organizations, by developing a generic ground station with associated standards.
- The TIRAMISU project (2012–2015) [38] considers the use of robotics assets (both ground and aerial robots) for specific types of crisis management operations, namely those where land mines and unexploded ammunitions pose a problem.
- The BerisUAS project (2014–2015) [39] investigated the potential of unmanned aerial systems for marine disaster response operations.
- The R^3 project (2014–2015) [40] aimed to develop a deployment model of robots in disaster management. Besides technical questions such as proper use cases, tactical, operational, and legal issues were also tackled.
- Inspired by the DARPA Challenge, the euRathlon project (2013–2015) [41] organized a competition for rescue robots, requiring a team of land, underwater, and flying robots to work together to survey a disaster scene, collect environmental data, and identify critical hazards. After the final euRathlon event in 2015 (discussed further in chapter 6 of this book), euRathlon transitioned into the European Robotics League for Emergency Robots [42].
- The CADDY project (2014–2016) [43] developed autonomous underwater and surface robots that act as companion to marine search and rescue divers. Note that this is one of the few European projects focusing specifically on marine search and rescue robots, whereas most others target mostly the land and aerial domains.
- The WALK-MAN project (2013–2017) [44] aims to develop a humanoid robot that can operate in buildings that were damaged following natural and man-made disasters.
- The TRADR project (2013–2017) [45] builds on the experience of the NIFTI project for human-robot collaboration in an urban search and rescue context, by building persistent environment models to improve team members' understanding of how to work in the disaster area. TRADR robots were successfully deployed in order to deal with the damage assessment operations after the 2016 earthquake in Amatrice, Italy.

- The RECONASS project (2013–2017) [46] developed a monitoring system, including unmanned aerial systems, that provides a near real time, reliable, and continuously updated assessment of the structural condition of the monitored facilities after a disaster
- The SHERPA project (2013–2017) [47] develops a mix of ground and aerial robotic platform which act as supportive agents to help in alpine search and rescue operations (winter and summer mountain rescue). Key research areas are robustness, autonomy, cognitive capabilities, collaboration strategies, and natural and implicit interaction between the human and the robots.
- The INACHUS project (2015–2018) [48] aims at providing wide-area situation awareness solutions, including novel snake-like robotic agents, for the improved detection and localization of victims trapped inside semi-demolished buildings.
- The Centauro project (2015–2018) [49] aims at the development of a human-robot symbiotic system where a human operator is tele-present with its whole body in a Centaur-like robot, which is capable of robust locomotion and dexterous manipulation in the rough terrain and austere conditions characteristic of disasters.

3. How does the European ICARUS project fit into the development process of search and rescue robots?

As can be noticed in the previous section, there is a vast literature on research efforts toward 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. Notable bottlenecks in the practical applicability of unmanned search and rescue tools are as follows:

- Slow deployment time of the current generation of unmanned SAR tools
- Limited autonomy and self-sustainability of the current generation of unmanned SAR tools, both from a point of view of the robot intelligence and from an energy and mobility perspective
- Limited collaboration between unmanned SAR devices
- Insufficient integration of the current generation of unmanned SAR tools in the C4I equipment used by fire and rescue services
- Insufficient support and training are available for the end-users to learn to use the unmanned tools
- Problems of interoperability of (unmanned SAR) equipment when multi-national crisis management teams need to collaborate on an incident site

The ICARUS project [50, 51] addressed these issues, bridging the gap s the research community and end-users. The ICARUS project was a completely end-user-driven project, where search and rescue workers expressed their operational needs, assisted with the development of solutions and defined and evaluated the developed components. The ICARUS project did not only focus on the development of tools and services, but also on the integration of these novel tools into the standard operating procedures of the end-users. Indeed, in many cases these integration issues, procedural incompatibilities or absence of legal framework are the main bottlenecks impeding a successful deployment in practical operations and not pure technological issues. ICARUS therefore concentrated also on placing novel technological tools into the hands of the end-users, thereby driving the acceptance and practical use of these tools. These end-user-related aspects of the project are discussed more in detail in the second chapter of this book.

Based on the operational needs of the end-users, the ICARUS project developed 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. As every crisis is different, it is impossible to provide one solution which fits all needs. Therefore, the ICARUS project concentrated on developing components or building blocks that can be directly used by the crisis managers when arriving on the field. By the end of the project, ICARUS had adapted three aerial robotic systems, two ground robots, and three types of marine vehicles.

On the aerial side, there is a solar aircraft, which beat the world record for continuous flight, staying in the air for a full 81 hours. The plane is 6 meters long, but only weighs 6 kg and fits into a small box when unmounted. It also has another important plus: it can fly at a low altitude, which makes it easier to obtain the necessary flight permits. The second unmanned aerial vehicle is an octocopter, i.e., an aircraft with eight rotors. Equipped with visual and infrared cameras, it can not only produce very accurate 3D maps of the environment for incident mapping but can also drop rescue kits. The smaller third platform is much more autonomous when it comes to taking decisions and navigating as it is designed to enter semi-destroyed buildings where the human controller is likely to lose communication with the device once on the inside. With a very powerful, yet light and power-saving stereo camera sensor on board, it can do 3D reconstruction in real time, a feature crucial for effective indoor navigation. The ICARUS aerial robotics developments are further discussed in the third chapter of this book.

In terms of ground vehicles, the project developed two kinds of platforms. The project's larger vehicle can break a building's wall to clear a passage to the people inside, clear away debris, or position pneumatic poles to stabilize unsound structures. A smaller vehicle that can go inside buildings is equipped with an arm for sensing and grabbing objects, as well as searching for victims. These vehicles are further explained in the fourth chapter of this book.

Finally, the consortium built three platforms for SAR operations at sea: a slower vessel for detection as well as for dealing with incidents close to the harbor, a very fast vessel, and "unmanned capsules," a smaller kind of boat carrying life rafts. The capsules can be deployed from the larger vessels. The faster vehicles get close to the victims, but remain at a safe distance from where the unmanned capsule is deployed, which can propel itself very close to the victim. There, it deploys the self-inflating life raft for the victims to climb on board. The development of the marine robots is explained in the fifth chapter of this book.

In order not to increase the cognitive load of the human crisis managers, the unmanned SAR devices were designed to navigate individually or cooperatively and to follow high-level instructions from the base station. Seamless interoperability between these different unmanned assets was a key focus point of the project, as further discussed in the sixth chapter of this book.

The ICARUS robots connect wirelessly to the base station and to each other, using a wireless self-organizing cognitive network of mobile communication nodes which adapts intelligently to the terrain and to the available spectrum topology, as detailed in the seventh chapter of this book.

The unmanned SAR devices are equipped with sensors that detect the presence of humans and with a wide array of other types of sensors. At the base station, all the data were 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. All this information is seamlessly integrated in existing information systems, used by the forces involved in the operations, as explained in the eight chapter of this book.

In the world of search and rescue, training is the key. Crisis managers will not use any tool on the field if they have not been extensively trained to use the tool. Therefore, ICARUS concentrated as well on the development of novel training tools, using virtual reality and e-learning in order to provide a quantifiable assessment of the capabilities of the rescue workers to work with the ICARUS robots, as explained in chapter nine of this book.

In order to validate the different ICARUS tools, two main demonstration scenarios were scripted by end-users: an earthquake response scenario and a shipwreck incident scenario. In this manner, an integrated proof-of-concept solution was proposed, evaluated by a board of expert end-users, ensuring that the real operational needs were addressed. Chapter 10 of this book reports on the outcome of these validation scenarios, as well as a real-life deployment of ICARUS tools during a flood relief operation in Bosnia-Herzegovina.

4. Conclusions

As proven by past successes and impressive research efforts around the world, unmanned robotic tools have a great promise to increase the effectiveness of search and rescue operations. However, there are still a large number of bottlenecks which prevent the successful introduction of these unmanned tools on the practical terrain. The European Union ICARUS project has tried to tackle some of these issues by following an approach of tight inter-relation with the end-users and of developing multi-tiered systems, i.e., making systems which are modular up to a certain degree, such that they can do multiple tasks, but not trying to do everything with one system, which would lead to an overflow of requirements. The following chapters in this book describe how this design approach was brought into practice and onto the terrain, even during disasters.

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