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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TIRAMISU : FP7-Project for an integrated toolbox in Humanitarian Demining, focus on UGV, UAV and technical survey

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Abstract

The TIRAMISU project aims at providing the foundation for a global toolbox that will cover the main mine action activities, from the survey of large areas to the actual disposal of explosive hazards, including mine risk education and training tools. After a short description of some tools, particular emphasis will be given to the two topics proposed by the GICHD Technology Workshop, namely the methodology adopted by the explosion of an ammunition storage and the possible use of UAV (or UGV/UAV) in Technical survey and/or Close-in-Detection

1. Introduction

The modular toolbox is described on www.fp7-tiramisu.eu while the following (non exhaustive) table gives a short description of the Technical Survey and Close-in-Detection tools

TID	Product Name (partners a.o.)	Current TRL	Expected TRL	Description Notes
T3	Ground Penetrating Radar Array (IDS) Ground Penetrating Radar Array: Signal processing module for classification (NOVELTIS)	4	6-7	Within the TIRAMISU project, IDS will build a modular, densely sampled, GPR imaging array with real time software for fully automatic detection of mines. The dense sampling and relatively large scanning width (1-2 m) of the GPR array will allow imaging capabilities, which through suitable advanced signal and image processing algorithms will be crucial for discriminating real mines, especially shallower and smaller AP mines, from metal fragments, rocks, roots or other soil heterogeneities (generally termed as clutter), thus reducing the usually high false alarm rate (FAR) of GPR. Could be combined with the tool T17 and mounted on a UGV
T4	Medium stand-off Synthetic Aperture Radar (DLR)	2-3	5-6	In this project DLR HR-AS will develop a vehicle-based side-looking imaging sensor (TIRAMI-SAR) based on the synthetic aperture radar (SAR) principle for the medium range detection of mines (5-15 m). This innovative solution can in fact solve critical problems encountered by previous attempts with SAR (very large distances from hundreds of meters to kilometres) while avoiding the criticalities of the forward looking scheme. Contrary to the military requirement, a humanitarian demining tool can be used to scan a long 5-7 m wide strip on its side from a safe lane in order to provide indication of suspected items for other tools to investigate further. In this way the system will serve as a very fast area reduction tool reducing hundreds of square meters of suspected land to a few spots requiring accurate close-in checks. It should be noted that SAR imaging requires a stand-off side-looking geometry, being completely different from normal close-to-ground GPR measurements. Consequently the use of the same vehicle in parallel for SAR and GPR is not possible

T7	Chemical sensor (USTAN)	2,3	6	To complement the well-established sensor technologies, we are developing novel polymer-based sensors for detecting explosive vapours from landmines. These sensors work by detecting a change in the light emission from a semiconducting polymer film [Thomas2007]. When exposed to very dilute vapours of TNT-like compounds, the explosive molecules adhere to the film and obstruct the light emission. Fluorescence sensing has previously been studied in laboratory conditions and in the field as the Fido sensor from Flir Systems. It was recently discovered that greater sensitivity is possible using laser light from the polymer instead of fluorescence to detect explosives [Rose2005]. Most research on light-emitting polymer chemical sensors has been laboratory-based and materials oriented. The research in TIRAMISU plans to advance the use of polymer laser sensors to minefield detection conditions for the first time, and will aim to establish the feasibility for new modes of application of laser and fluorescence array sensors including Technical Surveys of suspected mine fields.
T8	Remotely controlled Inspection Platforms (ISR-CSIC-RMA+)	4-6	7-8	UGV-UAV, Stand-Off UXO Sensor's carriers; read further chapter 2
T12	Low-cost agricultural derived assistance (DIMEC-PIERRE)	5	9	TIRAMISU intends to research breakthrough solutions for Technical Surveys based on agricultural technology, a complex of landmine absence verification assets and a new systematic methodology for the tracking and monitoring of the survey operations and for their planning. The implementation of a low-scale GIS system to collect real data on the trajectories of the assets and the area covered is a fundamental element that will complete an effective monitoring of operations and constitutes the basis for an informed land release planning.
T16	Intelligent Prodder (UNICT)	3	4 ,7	This device will be based on piezo- electric touch sensors with a simple yet effective methodology for feature selection and elaboration. Moreover, another advance will also be the integration of the prodder with other sensors such as force sensors and sensitive and highly directional electric field and magnetic field sensors. Therefore a multisensory data fusion technique will be implemented to improve the reliability of the system
T17	Innovative Metal detector Array (VALLON)	5	9	This research project focuses on a versatile and innovative multi-channel metal detector. The goal is to unify the advantages of a hand held detector (high detection performance, flexible adaption to terrain, various discrimination functions to enhance the detection capabilities by reducing the false alarm rate while keeping the probability of detection high) with the advantages of vehicle mounted multi-channel systems (large detection footprint, high search speed). This multi-channel metal detector is highly user configurable in terms of coil number, data interfaces and integration into multi sensor systems (with GPR, chemical sensors, etc

2. UGV

2.1 Introduction

The idea of using robotics for humanitarian demining and/or advanced light-weight modular low-cost robots for technical survey and/or close-in-detection has been proposed by numerous authors [Baudoin, 1999]. Even though none of the current robotics platform seem to have reached production on a larger scale (except for military EOD/IEDD tasks), many lessons may be learned from several projects and experiences. Robotics solutions properly sized with suitable modularized structure and well adapted to local conditions of dangerous unstructured areas can greatly improve the safety of personnel as well as the work efficiency, productivity and flexibility. In this sense, mobile systems equipped with manipulators for detecting and locating antipersonnel landmines are considered of most importance towards autonomous/semi-autonomous mine location in a proficient, reliable, safer and effective way. Conventional vehicle-mounted mine detector systems employ an array of sensor devices to achieve a detection swath typically 2~4m wide. Some systems employ more than one type of sensor technology. These systems, while being very useful are often expensive, unsafe, complex and inflexible [Ishikawa, 2005]. Nevertheless, several IARP (International Advanced Robotics Programme – http://iarp.isir.upmc.fr) workshops [Armada, 2005] [Fukushima, 2005] [Fukuda, 2005],[Fernández, 2011 have on the contrary shown that the use of Robotics Systems could improve the safety and the clearance efficiency and that they may be considered as promising tools.
One goal of the TIRAMISU project is to develop an advanced lightweight detecting system for humanitarian demining purposes consisting of an integration of three different sensors, a MD, a GPR and an explosives vapour detector (EVD). The final prototype (tool) would consist of a manned or unmanned vehicle-based system capable of detecting explosive devices (ED) with a higher clearance rate than that of the current level of technology.

2.2 Current R&D and Experiences of the TIRAMISU partners

2.2.1. ROBUDEM – TEODOR (RMA) [De Cubber, 2011]

Autonomous robotic systems operating in unstructured outdoor environments need to estimate the traversability of the terrain in order to navigate safely. Traversability estimation is a challenging problem, as the traversability is a complex function of both the terrain characteristics, such as slopes, vegetation, rocks, etc. and the robot mobility characteristics, i.e. locomotion method, wheels, etc. It is thus required to analyze in real-time the 3D characteristics of the terrain and pair this data to the robot capabilities.
To our knowledge, time-of-flight cameras have until now not been used for these kind of applications, simply because there were no sensors capable of coping with outdoor conditions, especially due to the interference of solar irradiation. This situation is changing now, with the advent of outdoor-capable sensors. Therefore, we now focus on an approach for outdoor terrain traversability which mixes 2D and 3D information for terrain classification.
Figure 1 shows the Robudem platform which is used as a testbed for the developed algorithms. It is a heavy outdoor robot equipped with a PMDTec CamCube time-of-flight sensor (on top) and a Point Grey Bumblebee stereo camera (in the middle). The time-off-flight camera is mounted in a tilted angle to avoid typical signal modulation problems. The top right image shows the amplitude input image, whereas the bottom left image shows the terrain classification result. Obstacles are red, well traversable terrain is green and "suspicious" areas (not enough data) are blue. It can be noticed that the classification is correct, as the obstacle (the tree) is well-detected. In the upper left corner, there are some problems with foliage giving erroneous reflections (blue area), which is due to the sensor
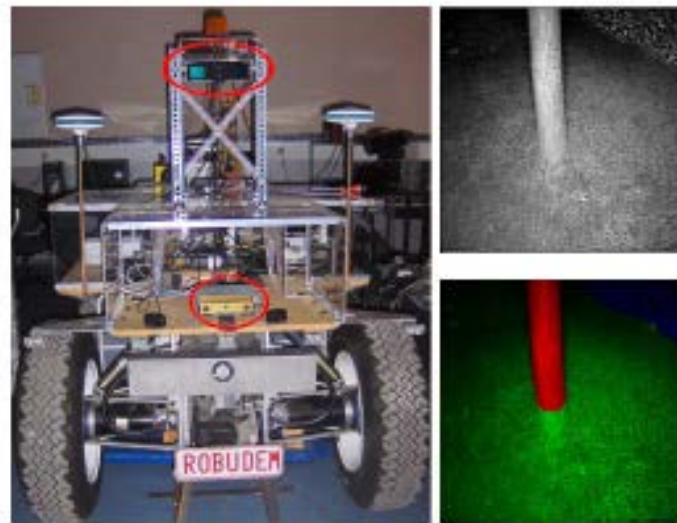
Figure 1: Left: System setup - Outdoor robot with a Time-Of-Flight Camera (on top) and a Stereo Camera (in the middle); Top Right: Amplitude Image; Bottom Right: Traversability Estimation (green: traversable; red: obstacle; blue: suspicious / not enough data)

2.2.2. LADERO – ISR-TT Robot

LADERO is an advanced multi-sensor demining robot designed and developed in ISR-UC Coimbra [Marquez,2002],[Rachkov,2005]. The robot can transport demining equipment up to 100 kg across rough and sloped terrains using its improved payload possibilities due to the robust design and pneumatic drive system. Robot pedipulators are adaptive to obstacles and terrain unevenness, so it can keep the working position of the mine detection block while searching for mines.

The design of the transport module of the robot consists of 200 mm stroke longitudinal pneumatic cylinders and latitudinal pneumatic cylinders whose bodies are connected symmetrically to cover maximum mine size in one stroke. Each pneumatic transport cylinder has two pedipulators that are fixed at ends of its piston rods. The pedipulator consists of 150 mm stroke lifting cylinder able to overcome stone obstacles of that magnitude and a foot with toothed contact surface to improve robot's climbing possibilities.

The detection block consists of a metal detector and VIS+IR detector [Larionova,2005]. This block is connected to the front part of the robot. A linear position sensor of longitudinal motion is placed on the body of the longitudinal cylinder. The linear position sensor of latitudinal motion and the detection block is placed on the body of the latitudinal cylinder. DGPS and IMU sensors provide self-localisation and an array of sonars provides obstacle detection around the robot.

The robot is controlled by an on-board processing unit and by an operator remote station in an interactive mode. Experimental results of the transport, control, and detection systems show effectiveness of their functioning. Due to the relatively low cost design, the robot application can potentially reduce demining costs. The robot motion and mine sensing are controlled by means of a distributed control system. This system provides remote control from a safe distance in an automatic mode or in a teleoperated mode by an operator. One of the main limitations of this platform is the requirement of air pressure supply through an umbilical tube, limiting the mobility of the platform to few tens of meters from the air supply.
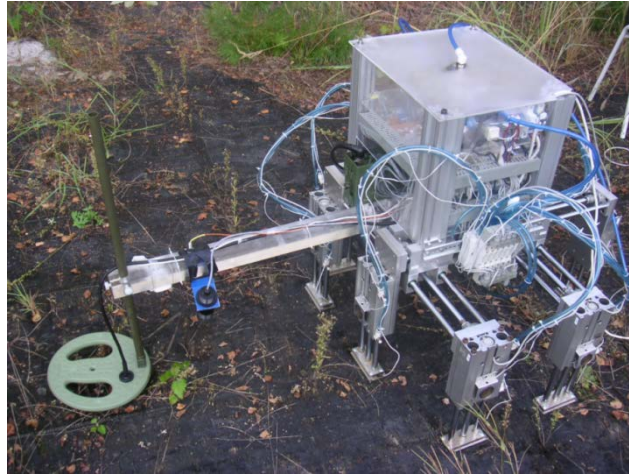
Figure.2. LADERO

The ISR-TT robot is an all-terrain 4 wheel drive mobile robot. Each wheel has independent direction and independent active and passive suspensions. The wheels are brushless DC (BLDC) in-wheel motors with 900W each. A total of 8 linear actuators composed by DC motors with position feedback are used for the direction and active suspension systems. This allows the 1m long robot to easily traverse rough terrain by shifting its body or by adopting diagonal trajectories. The robot can also perform in-place rotations. The high versatility of the ISR-TT robot translates into a wide range of terrains.

The total of 12 actuators are controlled by custom made intelligent DC and BLDC drivers that support CANopen communication. A CAN bus distributed across the whole robot, allows easy installation of new CAN-based sensors and actuators.

The ISR-TT robot is integrated into the ROS framework, making it easy to add or change sensors and actuators. The robot is equipped with a PointGrey Stereo System for obstacle avoidance and visual odometry. An Xsens MTi-G IMU provides global positioning (GPS) and data about the pose of the robot. Data from the IMU is also being fused with the visual odometry for generating more robust odometry estimation.

The ISR-TT robot can carry heavy payloads (at least 100kg) and can thus be equipped with a wide range of sensors for different missions.

Figure.3 ISR-TT all terrain robot for stand-off and close-in detection of ED (under construction).

2.2.3. DYLEMA (CSIC) [Armada, 2005] [Gonzalez de Santos, 2007]

The idea of using legged mechanisms for humanitarian demining has been under development for at least the last ten years, and some prototypes have been already tested. The Centre for Automation and Robotics – CAR (CSIC-UPM) holds experience in the design, development and control of walking robots, gait generation, terrain adaptation, robot teleoperation, collaborative control and other related fields. All these technologies were mature enough to be merged in order to produce efficient robotic systems, like the SILO6, a six-legged walking robot developed at CAR within the DYLEMA project (DPI2004-05824), specially designed for Humanitarian Demining. The DYLEMA whole system has been configured with the aim of putting together different subsystems (see Figure 2):

Sensor head, configured to detect potential alarms but also to allow the controller to maintain the sensor head at a given height over the ground using range sensors. It employs a standard metal detector for mine sensing.

Scanning manipulator, being basically the sensor-head a specialised stand-alone multi-sensor system, it is required to use a robotic arm to manoeuvre it through the desired space (3D position plus orientation), as well as to adapt it to terrain irregularities and to avoid obstacles.

Locator, the information provided by DGPS (Differential Global Positioning System) and electronic compass on board SILO6 is used after detecting a suspicious object to calculate and record their exact location in a database for subsequent analysis and decision-making.

Mobile robot, based on a six-legged walking robot, SILO6. A mobile platform to carry on the different subsystems across mine infected fields is of vital importance for thorough demining. The following characteristics are provided: hexapod configuration, enough lightweight to be handled by two adults, autonomous from the energy point of view, tethers are avoided, semi-autonomous from the control point of view, with a remote operator in the loop, power consumption, mobility and stability were balanced through detailed design.

Controller, the overall control system is distributed into two main computers, the onboard computer and the operator station. The operator station is a remote computer in charge of defining the mobile robot's main task and managing the potential-alarm database.
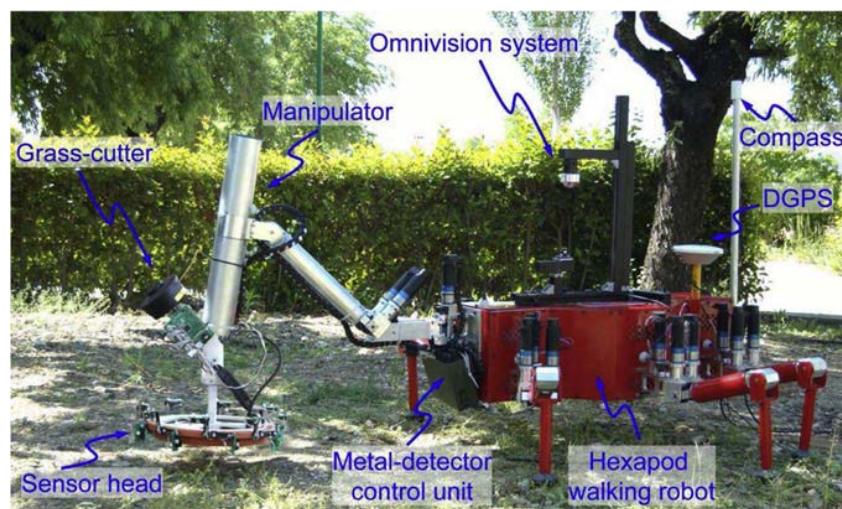

Figure 4. SILO6 Humanitarian Demining Walking Robot with Five Degrees of Freedom Scanning Arm.

2.2.4. LOCOSTRA (DIMEC, PIERRE, SNAIL-AID)

Machines for demining derived from agricultural tractors and using as tools modified agricultural implements are a promising direction for the development of sustainable solutions for supporting humanitarian demining operations.

One of the most relevant and pioneering systems is the platform LOCOSTRA, whose name stands for LOw-COst TRActor for Humanitarian Demining. LOCOSTRA is a tele-operated four wheeled machine design for technical survey. It is derived from a small agricultural tractor designed to operate in vineyards and orchards, the P796V produced by Pierre Trattori, with an hydraulic driveline and a double steering mechanism giving to the machine very high agility and controllability. This tractor is reversible (it can operate indifferently in both directions of motion); it is equipped with a standard three-points connection for the implements and it is characterized by a very high power/mass ratio allowing it to run heavy tools.

The demining version of this tractor is armoured and mounts wheels with an original design resisting blasts of antipersonnel mines. The user can tele-operate the machine from a long distance and basic operations are performed by LOCOSTRA autonomously.

The main functions supported so far are: the cut of the vegetation to prepare the minefield for technical survey, the treatment of the soil for the removal of mines, and the carry of tools for mine detection and localization. The ground engaging tools used are modifications of agricultural implements with similar functions: an armoured mulcher is used to cut the vegetation; a mine sweeper obtained from a modified potato-digger is used to harvest mines from the soil; a large loop detector is used to scan the soil.

LOCOSTRA has been tested with live AP mines in Jordan with the support of the national mine action centre and NPA Jordan in February 2011 and will be further improved under TIRAMISU.

Figure 4bis. LOCOSTRA in test

3. UAV

3.1. Introduction

The Micro-mini UAV (MAV) and Rotary Wings seem to be good candidates for Technical Survey and, possibly, Close-in-detection in Humanitarian Demining while the MALE (Medium Altitude Large Endurance) and SR (Short Range) or MR (Medium Range) could be envisaged for the Non-Technical survey

The small size of MAVs has several implications on their performance capabilities. First and foremost, they have limited payload capacity (size, weight, and power) and are therefore unable to carry significant computational resources or sensors of the highest accuracy and capability. Second, their small size and relatively low flight speeds make them susceptible to degraded performance caused by high winds and wind gusts. These challenges, imposed by the small size of MAVs, must be overcome for MAVs to be utilized successfully. Future advancements in miniaturization and performance of sensors and computers will enable increased success. However, efforts must also be made to utilize existing sensor and computer capabilities in novel and innovative ways to enhance the utility of MAV systems in the immediate future [Gerard ten Buuren, 2011]

The ability to land a MAV accurately on a designated landing point is useful for several applications including the safe recovery of the MAV in risky conditions (a.o. minefields)

Several challenges make precision landing/strike difficult for small UAVs. The disturbance imposed by wind is always an issue with MAVs, and for the present, sensor errors such as those common in the measurement of attitude and altitude cause difficulties. For precision landing, the most critical information is to know the location of the MAV relative to the desired landing location. Developing reliable methods for measuring this information is central to the success of a precision landing approach.

The value of target (Explosive Device) tracking and localization from a small MAV platform is obvious and significant. this capability is attractive, but presents challenges.

The most significant challenges associated with accurate target localization stem from the lack of precise attitude estimates for the MAV platform. Pitch and roll are difficult to estimate with a high degree of accuracy with the Micro-electromechanical systems (MEMS) sensors typically used for MAV control. Measurements of heading are not available – heading is often approximated by the course of the MAV which is estimated from successive GPS measurements. In high-wind conditions (relative to the desired airspeed), the course is often a poor approximation of the heading.

The ability to operate in constrained environments is of great importance for MAV that must be able to fly amidst natural and man-made obstacle

Air-to-ground detection systems could provide an interesting contribution to the technical survey as well as to the close-in-detection aims for so far technical and operational improvements are precisely defined. Both the aerial platform (a sensor's carrier) and the Remote Pilot Station have to be considered, both in the context of evolving legal (national, European and/or international) regulations.


3.2 Experiences

3.2.1. ROBOVOLC (UNICT) (sample gathering)

The project ROBOVOLC is a project lead by the University of Catania in cooperation with the INGV (Italian Institute on Geophysics and Volcanology) since 1998. The project has been initially funded by the European Commission within the 5th Framework Programme. The main purpose was to develop a robotic system for measurements and explorations in a volcanic environment [Guccione, 2000]. The final system developed is a six-wheeled robot with an articulated chassis and a five degrees of

freedom manipulator arm, used to collect rock samples and to perform gas measurements [Muscato, 2012].

| Figure 5. ROBOVOLC in action on Mt. Etna. | Figure 6. The U-Go Robot. |
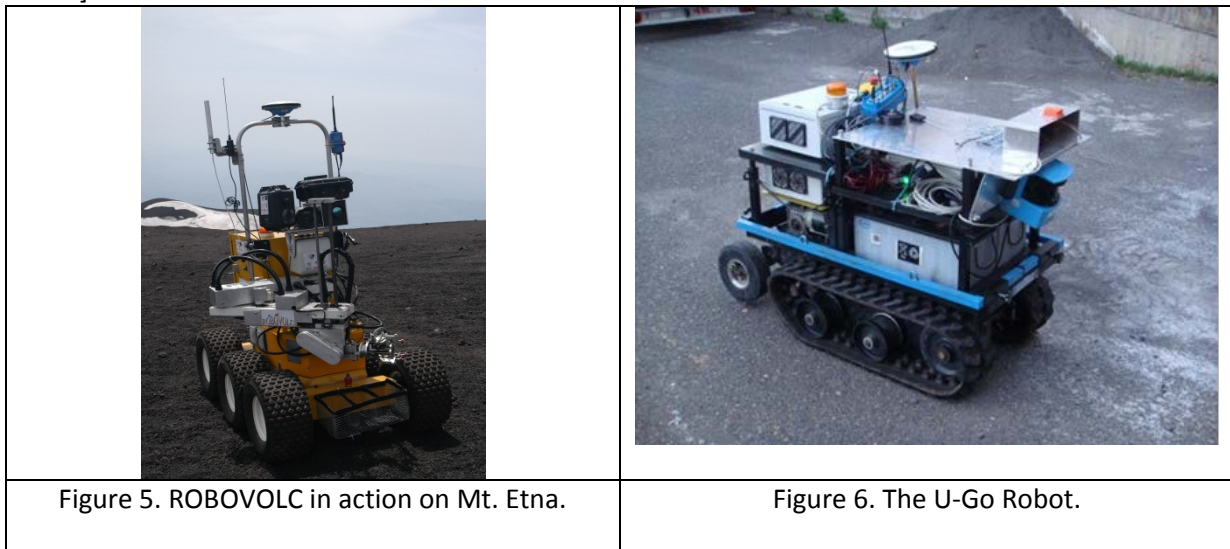
Several science sensors are mounted on ROBOVOLC and comprises a pan-tilt turret, a manipulator, and a gas sampling system. Mounted on the pan-tilt turret, is a video-camera with recorder, a high resolution still-image camera, another video-camera for teleoperations, an infrared camera for thermal measurements, and a Doppler radar for lava and gas-jet speed measurements.

The ROBOVOLC is usually teleoperated, but in some situations is fundamental to move it autonomously. So a navigation system has been also installed including a stereo camera (Videre, STH-MDCS3-VAR), an Attitude and Heading Reference System (X-Sens MTi), a Laser range finder (SICK LMS200), US-Sonars (Devantech SRF08), a Global Navigation Satellite System receiver RTK-DGPS (Ashtech ZXtreme) and Encoders on each wheel.

Recently another platform has been developed for volcanic exploration and **agricultural** applications. This new robot named U-go, has a simpler mechanical structure using two independent tracks, but adopt the same navigation architecture developed for the ROBOVOLC [Bonaccorso, 2011].

At University of Catania a research line for the development of UAVs for volcanic inspections was also started. In particular the Volcan Project was initiated in cooperation with INGV, with the aim of building a series of autonomous flying system to perform gas analysis and sampling and visual monitoring of volcanic areas [Astuti, 2009].

Due to weight and space limitations, UAV cannot have on board precise DGPS or other big or heavy sensors. On the other side UAV are very useful to give a wide map of the interested environment that could be really useful to plan a mission. Consequently we developed some SLAM algorithms that could merge precise localization information from the UGV with aerial information of the UAV [Bruno, 2008].
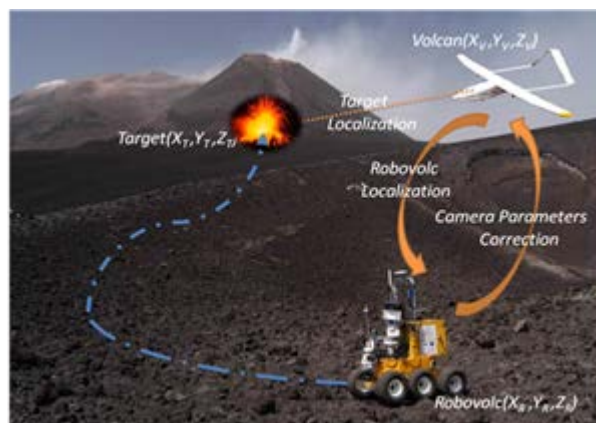
Figure 7. UAV/UGV cooperation.

3.2.2. ROBOT FLEETS FOR HIGHLY EFFECTIVE AGRICULTURE AND FORESTRY MANAGEMENT [González de Santos, 2011]

The DUAL use aspects of the TIRAMISU toolbox has been underlined in the so-called 'restoration of the environment, promoting a sustainable economic and social development'. Agricultural technologies are largely available everywhere and at different levels. Where they are
not already available, their presence might be desirable to increase the capability to produce
food by farm mechanization. In this context, synergy with other FP7 projects of the TIRAMISU partners will serve our aims.
RHEA project "*Robot fleets for highly effective agriculture and forestry management*" (FP7-NMP2-LA-2010-245986), co-ordinated by CSIC [González de Santos, 2011], is focused on the design, development, and testing of a new generation of automatic and robotic systems for both chemical and physical (mechanical and thermal) effective weed management. This focuses on both agriculture and forestry and covers a large variety of European products. A fleet of small, heterogeneous ground and aerial robots are used, equipped with advanced sensors, enhanced end effectors and improved decision control algorithms (See Fig. 1). RHEA can be considered a cooperative robotic system, falling within an emerging area of research and technology with a large number of applications. One of the RHEA scientific and technical objectives is focused on advanced systems and algorithms for weed mapping based on computer vision in two modes: remote sensing (information gathered by means of aircrafts or UAVs) and ground sensing (information collected from ground robotic platforms, as it is illustrated in Figure. XX. Remote sensed imagery acquired with mini aerial vehicles, in conjunction with GIS technology enable a meticulous analysis from surveyed agricultural sites [Valente, 2011].

Figure 8. RHEA fleet concept

3.2.3. The DIVA Airship

The DIVA project focused on the establishment of technologies required to substantiate autonomous operation of unmanned robotic airships for environmental monitoring and aerial inspection missions. This includes developing a prototype and its sensing and processing infrastructures, control and guidance capabilities, and the ability to perform mission, navigation, and sensor deployment planning and execution. [Mouthino, 2008],[Mirisola, 2008-2009]
The DIVA remotely controlled non-rigid airship has a helium filled envelope with 18m3 volume. It is 9.4m long, with 1.9m diameter. Its maximum speed is around 70km/h and the maximum height

during remotely piloted flights is 200m above the ground, corresponding to an altitude of approximately 300m.

The airship is propelled by two internal combustion motors with propellers, and controlled by standard aero-model equipment. Servo motors are used as actuators, to control the motors acceleration and steer the airship with the flaps mounted in the back of the envelope. A human pilot with a radio control unit sends commands to an on-board radio control receiver to control the servo motors. The combustion motors and electronic equipment are mounted on a gondola, below the envelope, which may have a maximum weight of 13.5kg. Thus discounting the weight of the mechanical structure of the gondola, motors and aero-model equipment, the payload available for electronic equipment and sensors is about 7kg. The blimp carries a digital camera, rigidly mounted with an AHRS, and a GPS receiver, among other sensors, plus an embedded CPU with flash memory storage to read and store sensor data and images, and radio Ethernet equipment to communicate with the ground.

A ground station, consisting of a laptop connected to a wireless Ethernet access point with a 7dB antenna, receives telemetry data during the flight, and displays it to the operator, who is able to check the operation of all sensors before taking off and monitor the telemetry data during the flight.
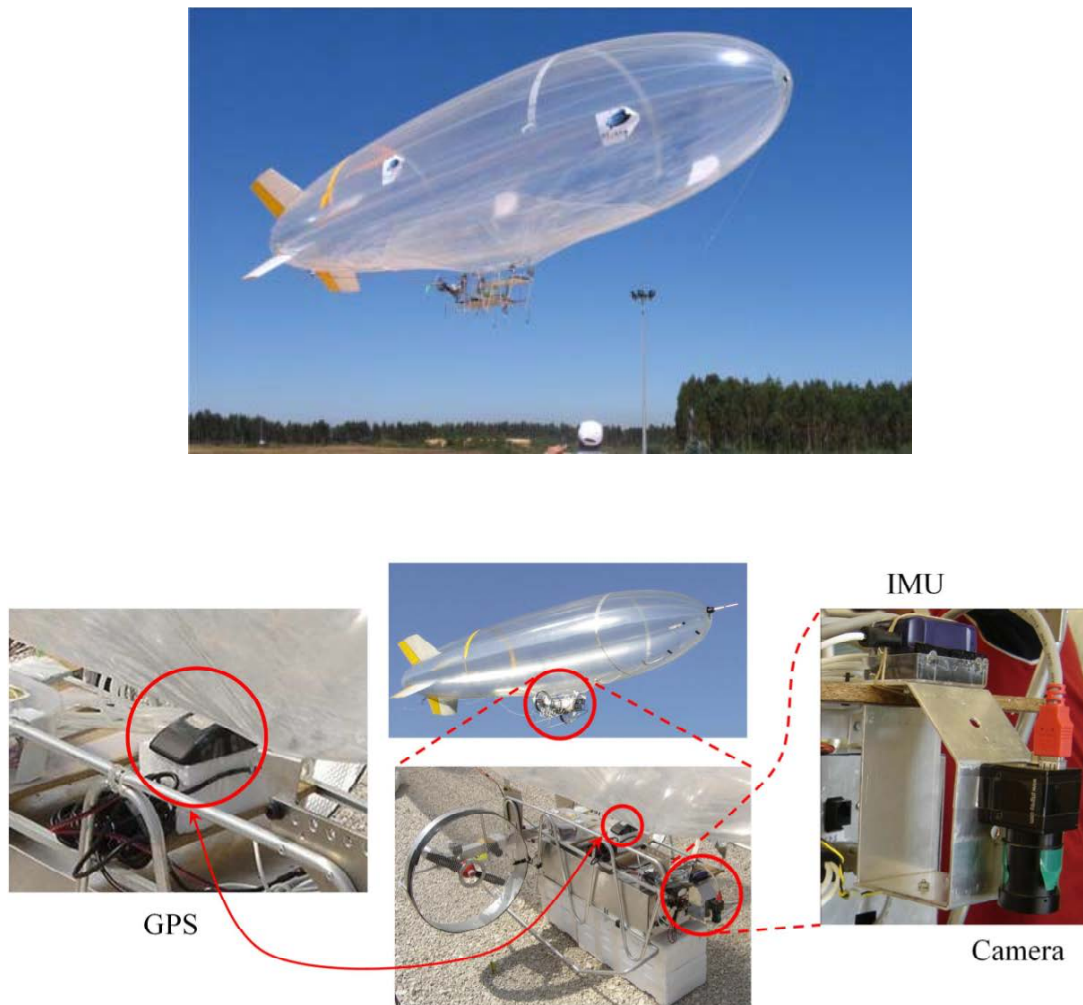

Figure 9. DIVA airship with details of some of its elements.

3.2.4. The Gyropendulum – Minemarking project [JM Desaulniers, 2012]

The Gyropendulum MineMarking Platform (dimension 1.5m x 1.5m - weight range 12kg-24kg) is a Multi-Modal Multi-Media Craft Platform, supporting the Gyropendulum Concept (see FIG. I), that provides the ability to evolve into harsh environment with higher stability than standard platform. Its design authorizes the adjunction of different applicative payloads (weight of 1kg up to 2 kg) that may be fitted into a cylindrical cavity of variable size (diameter of 30mm up to 100mm) according to the targeted application, located within the central body of the Gyropendulum Craft Platform. It operates as a high endurance manual or semi-autonomous platform, radio-controlled by a local pilot over a range of action or search cell determined by an ultra light / high efficiency umbilical power cable (length of 20m up to 100m) that provides redundant secured single phase 220v AC 32 amps. It is built around a rugged carbon fiber central body (height 1.5 meter) that may handle substantial shocks and vibrations. The six propulsors (three on lower and upper propulsion groups) with static or dynamic tilt adjustment are composed of axial 220v AC motorizations with speed reducers and high resistance tri-blade propellers.

Such platform may be equipped with various sensors types (optical, acoustic, X-Ray,…) with peripheral or facing ground configuration in order to assess the 3D characteristics of the terrain,
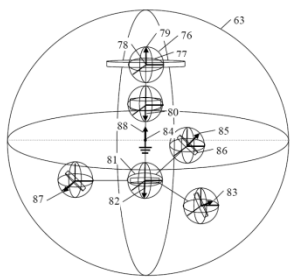

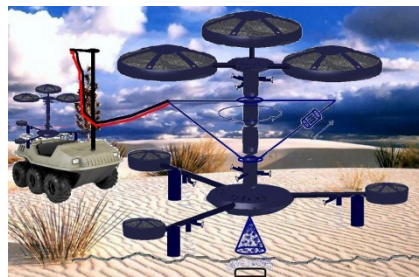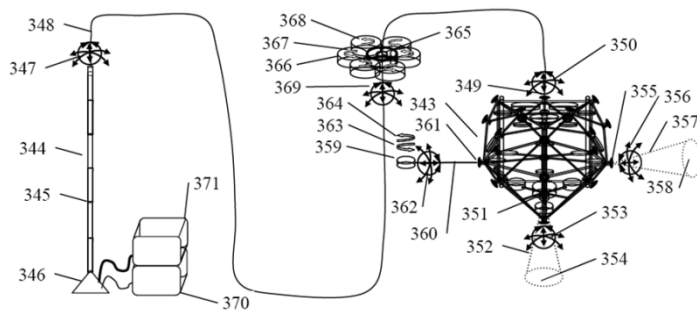FIG. I – Gyropendulum Concept   FIG. III – Gyropendulum MineMarking Platform

FIG. IV – Very first prototype of Gyropendulum MineMarking Platform 220v AC with Umbilical Cable

Figure 10. The Gyropendulum of JMDThèque

obstacles and targeted objects. For MineMarking application the platform is equipped with a pressured paint reservoir and injector enabling spot generation (diameter from 3cm up to 50cm) by spraying "normal" above the targeted area/surface (distance of 20cm up to 1m). A specific manipulator (i.e. light robotic arm, low or high precision hexapod,…) may be adapted to the side (radial configuration) of the lower plate or below it (axial configuration). An optional autonomous multicopter power cable lifting/guiding unit (see FIG. II N°367) may be added to the Gyropendulum MineMarking Platform. The 220v AC 32 amps power source may be static or mobile, i.e. installed on a six wheel vehicle with or without pilot or a dedicated UGV. The semi-autonomous mode provides in-built stability/locomotion feature (Steady-NAV[TM]) and obstacle detection with auto avoidance/rerouting in-built mechanism. It may support pre-loaded or on-the-fly GPS coordinate

trajectory planning/processing as a flight/detection assistance feature requiring pilot confirmation on a per command basis when critical/unknown situation occurs.

Steady-NAV[TM]**,** is responsible for computing in real-time resultant forces, couples/torques/moments, radius of gyration, according to its center of gravity and mass distribution, to be applied to the Gyropendulum Craft Platform.

Umbilical Cable, is a flexible semi-rigid pvc annular isolated component supporting high current that provides partial self-supported feature in order to avoid multiple knots, overstress due to bad flexion (radius of curvature that would be too low) or excessive torsion, as well as thermal dissipation/regulation feature. The resilience / weight ratio is specific on a per application basis. It requires multiple high grade copper or aluminium conductor with a weight characteristic that should be within the range of 850-1200gr per 25m section. Typically, one umbilical cable involves three up to six conductors according to the configuration (total platform current consumption range of 32amp up to 64amp).

Power System 220v AC 32amp, is responsible for providing a clean stable 220v AC sinusoidal waveform with high rate varying alternative current from 12amp up to 32amp.

Propulsion Group Modularity, enables the Gyropendulum Craft Platform to be equipped with motorizations ranging from 500 watts up to 2400 watts and typically with the following tri-blade propellers configurations (32cm-18cm, 36cm-18cm, 40cm-20cm) according to the required thrust per propulsor within each propulsion group (upper and lower) on a per application basis. Each propulsion group may involve from three up to six propulsors.

Craft Platform Squeletton, is designed and built on a per application basis with a mix of layered carbon fiber and aluminium according to the sustainable severity of the environment/weather (wind force/rate/pattern according to terrain topography, rock walls, buildings, infrastructures, trees, bushes, and other fixed or mobile obstacles), as well as the targeted achievable flight domain (from low to high translation/rotation/inclination transition rate defined by thrust/roll/pitch/yaw commands/ actuations associated to a specific trajectory spline).

Locomotion, is provided through real-time pulsed modulation of each propulsor associated to static or dynamic actuators that may re-orient each vortex separately according to initial configuration, in order to impulse a specific discrete translation/rotation/inclination to the Gyropendulum Craft Platform.

4. Airborne hyperspectral and the multisensor assessment of the unexploded ordnance litter at and around the ammunition storage after the accidents

The large quantities of ammunition that are surplus or have exceeded their design life, should be safely disposed or destroyed, although the undesired accidents, explosion of ammunition storages happen very often [GIHCD, 2002], [UNDAC, 2008]. The frequency of the storage explosions increases due to other reasons too (e.g. Libya, Syria) and the new technical solutions are needed to advance the current practice, in which dominates visual search supported by metal detectors for assessment of the contamination distribution, marking, manual displacement and destroyment. One important need is the wide area general assessment of the impact of the undesired ammunition storage explosion on the citizen's security and environment. The natural approach is to consider the aerial remote sensing, but there is no available the operational technology. The overview of the public references shows that there are no direct solutions for the considered problem. There are several general references about the status of the afflicted area after the undesired explosion, e.g. [GICHD, 2002], [UNDAC, 2008]. The wide area assessment of military test ranges for training of airborne bombing, for testing the artillery, mortars, missiles and other weapons is mature technology, which is mainly based on the magnetometers (ground based – towed, and airborne). The airborne techniques for detection of unexploded ordnance and particularly the detection by means of the hyper spectral remote sensing, is considered in [Doll et al. 1999], [Foley 2007]. Note once again, that the

mentioned technologies are suited for test ranges and not for scattered unexploded ordnance after the undesired explosion of the ammunition storage.

This problem was recognized and one task was included in EU FP7 project TIRAMISU (www.fp7-tiramisu.eu). This task was driven by the undesired explosion 13.09.2011 of the ammunition storage Padjene, Croatia, which serves in TIRAMISU as the case study area.

The afflicted region after the explosion covers area 38,5 km^2, this is the ammunition storage and the area inside of circle with radius 3.5 km. The initially estimated density distribution of the UXO litter, measuring from the center of the ammunition storage is: inside radius 800 m – 70 %, from 800 to 1000 m – 20 %, from 1000 to 2000 m – 6 %, from 2000 to 3000 m – 3 %, from 3000 to 5000 m – 1 %. The success of the application of the airborne multisensor system for the needs of the humanitarian demining [Bajić 2010], is a strong reference which enabled to derive proposal for the inclusion of an improved task in TIRAMISU.

A   B

Figure 11. Ammunition storage Padjene a) 29.03.2006, before the explosion (Google Earth), b) aerial photography 13.10.2011, after the explosion 13.09.2011.
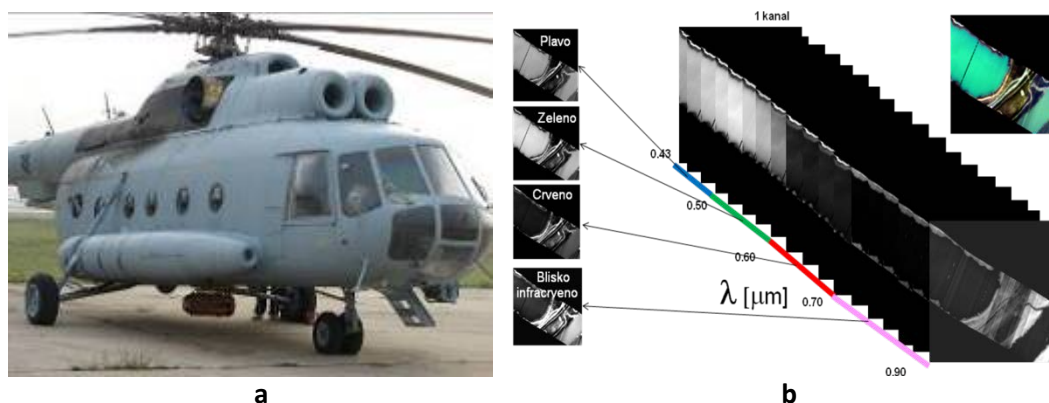

a   b

Figure 12. Airborne system for the hyper spectral and multisensory imaging [Bajić M., 2010]. a) Sensors are in the pod, bellow the fuselage of the helicopter Mi-8. b) The hyper spectral imaging provides 95 images of the imaged area after the correction of the atmospheric influence, parametric geocoding and matching to the spectral samples of the targets collected on the ground.

In the case of the humanitarian demining the targets are remains of the war at the mine suspected area (trenches, shelters, bunkers, etc.), while in the case of ammunition storage explosion are

different types of UXO, propellant, packing. These targets are mostly smaller and there is a main problem how detect them, recognize and describe with needed probability.

The Johnson's criteria [Holst, G.C., 1996] can serve as a guide for definition of needed spatial resolution for required probability of detection, recognition and description. The opposite problem is how to enable coverage of a wide area with needed spatial resolution of the sensors on the aerial platform. Whatever aerial platform is used, the blurring the images due to the vibration is unavoidable. We have derived very efficient compensation of the vibration with passive dumping vibrations of the helicopter Mi-8.

Next problem is how to discriminate litter of UXO, propellant, packing on the terrain around the exploded storage. The difference of the spectral response between the targets (aerial bombs, cluster ammunition bombs, shells, mortar mines, missiles, their litter, propellant) and the soil, the vegetation increases probability of detection, recognizing and the description of these targets. The samples of the coefficient of reflection of considered targets have been collected on the ground (end members), Fig. 13, and the hyperspectral aerial images have been collected by system shown at Fig.12. The other sensors in the airborne system acquire images in the same flight and conditions like the hyper spectral imaging sensor. The dimensions of the smallest target determine altitude above terrain which provides needed

Figure 13. Measurement of the coefficient of reflection by line scanner. Different types of UXO have been measured.

spatial resolution and enables required probability of the detection, recognizing and technical description. The fusion of the hyper spectral and multisensory imagery provides more information then the simple sum of the results provided by each sensor separately. The acquisition phase was finished in June and July 2012 and now follow processing and interpretation.

5. Acknowledgment

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