TIRAMISU-ICARUS: FP7-Projects Challenges for Robotics Systems

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ABSTRACT

TIRAMISU: Clearing large civilian areas from anti-personnel landmines and cluster munitions is a difficult problem because of the large diversity of hazardous areas and explosive contamination. A single solution does not exist and many Mine Action actors have called for a toolbox from which they could choose the tools best fit to a given situation. Some have built their own toolboxes, usually specific to their activities, such as clearance. 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. The toolbox produced by the project will provide Mine Action actors with a large set of tools, grouped into thematic modules, which will help them to better perform their job. These tools will have been designed with the help of end-users and validated by them in mine affected countries.

ICARUS: Recent dramatic events such as the earthquakes in Haiti and L'Aquila or the flooding in Pakistan have shown that local civil authorities and emergency services 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 (both in human lives and in €) of a major crisis. In order to realise 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 and to assist search and rescue teams for dealing with the difficult and dangerous, but life-saving task of finding human survivors. 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. The ICARUS tools consist of assistive unmanned air, ground and sea vehicles, equipped with human detection sensors. The ICARUS unmanned vehicles are intended as the first explorers of the area, as well as in-situ supporters to act as safeguards to human personnel. The unmanned vehicles collaborate as a coordinated team, communicating via ad hoc cognitive radio networking. To ensure optimal human-robot collaboration, these ICARUS tools are seamlessly integrated into the C4I equipment of the human crisis managers and a set of training and support tools is provided to the human crisis to learn to use the ICARUS system.

INTRODUCTION

The year 1994 may be considered as the first decisive year in the long struggle with the use and the removal of anti-personnel (AP) mines throughout the world, followed in 1999 with the Entry into force of the OTTAWA Treaty adopted on September 1997, the Convention on the Prohibition of the use, stockpiling, production and transfer of AP-mines and their destruction. Today the mine ban treaty counts 161 States Parties [1]

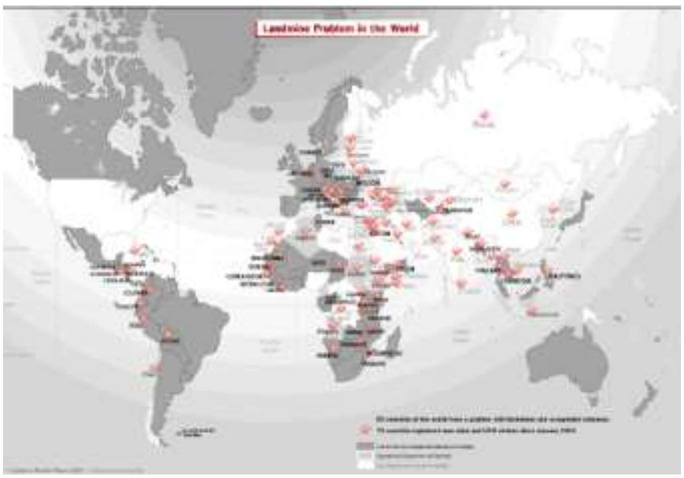

Figure 1. Affected countries and OTTAWA-OSLO partners

As shown on the previous map, let in white, thirty-six States still remain outside of the Ottawa Treaty: a political problem. As shown also on this map summarizing the problems detailed on www.the-monitor.org, 58 Countries are still affected by unexploded remnants of War and Conflicts

1999: UNMAS and the Geneva International Centre for Humanitarian De-mining Decided to develop and maintain an Information Management System for Mine Action (IMSMA)
The land release concept has evolved over the years and now usually involves several steps as outlined in the following diagram

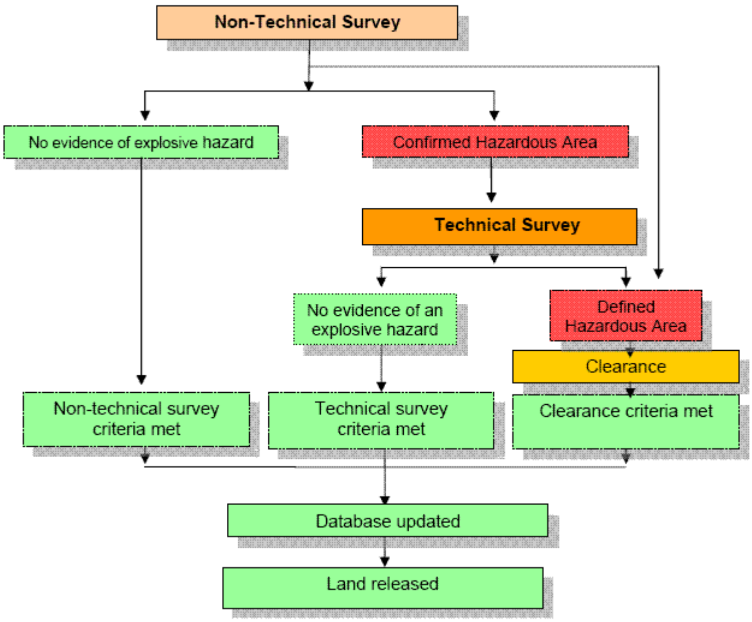

Figure 2 Land release concept (IMAS 08.20)

Following a high level analysis of the risk factors and socio-economic interests (Advanced General Survey) so as to prioritise the suspected hazardous areas, a **Non-Technical Survey** is performed to collect and analyse new and/or existing information about a suspected hazardous area. If no evidence of an explosive hazard is found, then the area is released. Otherwise, an intervention with limited clearance or verification assets is carried out (**Technical Survey**) which may lead to the conclusion that there is no evidence of an explosive hazard and that the land can be released, or, if evidence is found that the area, or part of it, should actually undergo full **Clearance**. Robotics Systems could be proposed for the last two steps, Technical Survey and Full Clearance (including Close-in-Detection and Disposal of Explosive Devices)

March 2009 was the first deadline for completing clearance by the mine affected countries that ratified the Ottawa Convention before March 1999. Unfortunately, two thirds of them have not met this deadline. Fifteen countries have asked for an extension of the deadline (by one to ten years), leaving for many of them a great percentage of their territories unsafe, and committing their weak economies to support expensive Mine Action practices for a longer period of time. March 2013, new countries have been affected by the plague of disseminated unexploded devices, landmines but also cluster munitions (now directly concerned by the OSLO Treaty). New dangers arise in some North African Countries, Middle East and Asian Countries , called Improvised Explosive Devices (IED) and slowing the difficult tasks of Deminers.

TIRAMISU

The TIRAMISU (Toolbox Implementation for Removal of Anti-Personnel Mines, Sub-munitions and UXO) 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 Training and Mine Risk Education.

The project is supported by a Project Advisory Board composed of Scientists and Stake-holders, among which Management Information Specialists of the GICHD, experienced experts in Robotics [3] and the Belgian EOD/IED service of the Belgian Defence (DOVO), particularly active through Humanitarian Mine actions-missions over the world (figure 3)

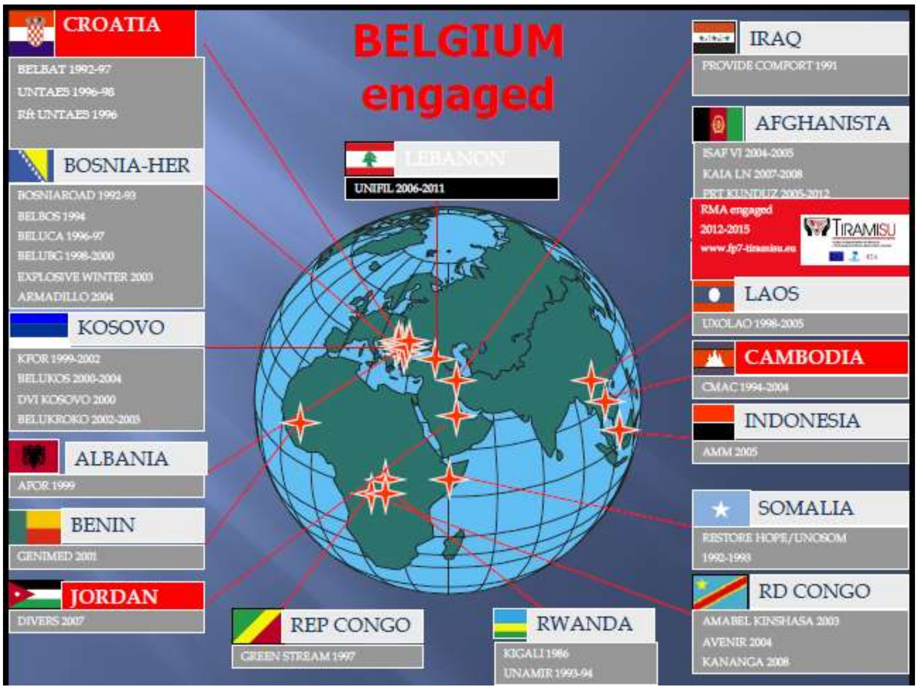

Figure 3. Demining missions entrusted to the DOVO

Croatia, Jordan and Cambodia will be the privileged partners of the TIRAMISU consortium for the final validation tests that will take place in 2015.

TECHNICAL SURVEY

The Technical Survey comprises the intervention with clearance or verification assets into a CHA (Confirmed Hazardous Area), or a part of a CHA, with the main purposes:

(1) to confirm the presence of mines and ERW (eventually identifying the type of hazards and the boundaries of the hazardous areas) which will then require clearance, and/or

(2) to increase the confidence to help justify decisions on the release of land, and/or

(3) to give to the local people sufficient confidence to use a land without restoring to full clearance techniques.

The main purpose of the equipment for Technical Survey is to collect information or clues about the presence and rough location of explosive hazards in the CHA

To combine the objectives of the Technical Survey with the possibility to convert the developed tools for further agricultural exploitation, TIRAMUS focuses on remote piloted aerial systems (RPAS) and also on the use of semi-autonomous Land platforms, among which agricultural platforms with introduction of automation processes in their control.

SEMI-AUTOMATIC AGRICULTURAL VEHICLE

The agricultural machine should be cost efficient, easy to transport (small size, light-weight), fail-safe and low-cost (use of off-the-shelf components), not complex, easy to repair, easy and cheap to maintain. A very important issue is fuel consumption. The machine should operate for a long and continuous time between refueling. For the purpose of this project the P796V tractor, developed by PIERRE TRATTORI DI GIOVANNI BATTISTA POLENTES & C SNCl will be modified to host:

- an **industrial dual remote control** (This means that no manual on-board controls are removed, and the operator can either drive the tractor on board or operate it remotely) with maximum control distance >100m,
- a **light armouring** accurately protecting critical parts,
- **new innovative blast resistant wheels**, able to reduce the shock wave associated with an explosion underneath as well as dump dangerous vibrations, keeping the chassis and the tractor mechanics safe, tested very successfully against 280g of TNT underneath,
- **agriculture derived implements**, and
- **close-in-detection tools**

According to [4] (depending on the implements attached) the tractor based platform can be categorized as clearance machine, ground preparation machine (multi-tools), ground preparation machine (vegetation cutter) or mine protected vehicle. Further it can be sub-categorised as: intrusive to the mined area – designed to work inside the mined area, remote operated – designed to work remotely from the driver/operator position either and driver operated – designed to be controlled by a driver/operator in a cab either.

Figure 4 P796V tractor – base for the platform

Tractor's frame is entirely made of steel allowing the use of relatively heavy attachments. A standard, category I, three point linkage attachment at the rear, allows hydraulic lifting and positioning of most off the shelf agricultural tools. Power to the attachments is drawn from a power-take-off (PTO), also available at rear of the vehicle. Being the frame reversible, i.e. the driving position invertible, the same power take off can be used to carry tools at the front, i.e. to cut vegetation in front of the machine. The machine is designed to be easily transported over unimproved terrain without the need for a dedicated transporter. It will be equipped with two sets of wheels, four traditional pneumatic wheels and four blast resistant wheels. Pneumatic wheels can be used on paved roads for medium distance travel, while blast resistant wheels are used in suspected hazardous areas.

 	 	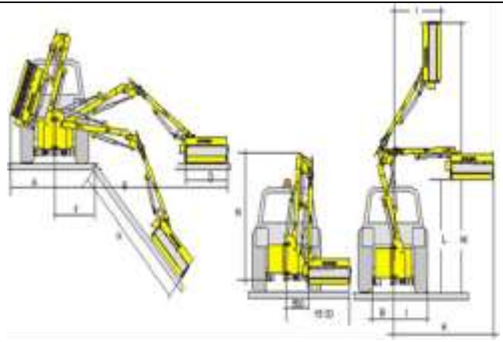
Potato digger SPEDO, model CPP-BD-150 (above); forest shredder FAE: UML/ST 150 (below)	Disc plough (below); mounted vibro-tiller (above)	Hydraulic brushcutter

Figure 5. Implements

MINI REMOTE PILOTED AERIAL SYSTEM

An initial feasibility study was carried out to assess the possibility to operate a compact polymer laser sensor **for explosive vapors on a low-cost micro-aerial vehicle (MAV or RPAS). While the vapor sensors are planned to** be used in several different configurations within the project, this particular potential implementation is the most demanding in terms of low mass and low power consumption. The intended RPAS will be the ORBIT Geospatial technologies , with an optimal payload of less than 1 kg, a maximal payload of 2kg and an endurance of 80 minutes. To assess feasibility we surveyed the mass and power consumption of a range of compact system configurations that are known to be suitable for optically pumping polymer lasers. It should be noted that not all of these configurations will be adequate for the current best sensing materials used by the USTAN (THE UNIVERSITY COURT OF THE UNIVERSITY OF ST ANDREWS). We can conclude from this initial study that, system with mass of 2 kg is certainly feasible, but may exclude use of some of the most sensitive sensor materials. A compact system of mass around 5 kg should allow flexibility for most candidate sensor materials. Using current demonstrations of compact configurations of polymer laser systems it is unlikely that it will be possible to make a laser vapor sensor with the required target mass of 1000 g for operation on a MAV. Some reduction in weight could be possible for sensing systems based on fluorescence rather than lasing, but this is likely to come at the expense of response speed and sensitivity (and hence require longer measurements in limited flight times).

The feasibility study also identified a further significant obstacle of operating a vapor sensor on a MAV. Helicopter based MAVs generate a significant down-draft from the rotors. The turbulent atmospheric flow away from the MAV is expected to seriously interfere with detection of vapors.

At present the application of operating the polymer vapor sensors on a MAV has serious feasibility problems. Substantial work is planned to test limits of the sensitivity of the laser and fluorescence sensors during the next phase of the project. This will provide essential information on the sensitivity and required measurement times- two parameters that must also be assessed to establish whether MAV operated explosive sensors are ultimately feasible.

However, we note that for implementation in the technical survey, an alternative scenario would be to use the MAV as the vehicle for REST (Remote Explosive Scent Tracing) sampling. This approach still has the potential difficulties related to downdraught, but it conceivably may be possible to use the dynamic airflow to collect samples in a REST filter. The sensing for explosive material would then be undertaken in a second step when the MAV returns the REST sample to base. The next figure illustrates the REST technique: note that the device may also be considered as an implement for the above described tractor.

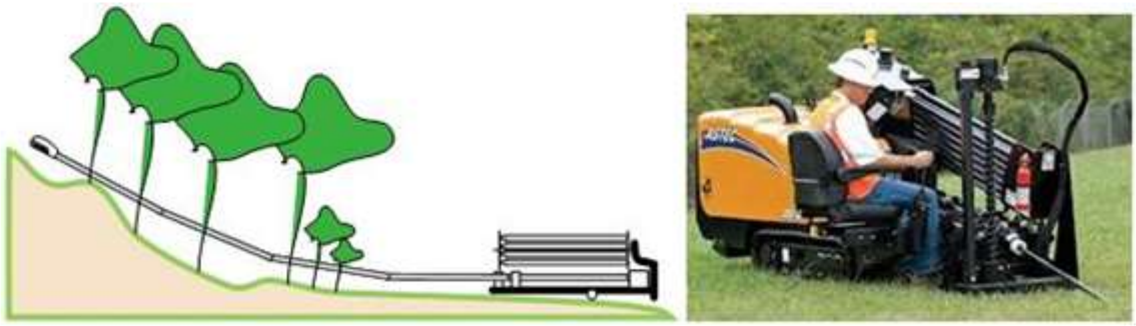

Figure 6. Schematic of the automatic REST sampling method (left), and example of drilling machine used as reference for the development of the REST system (right)

In TIRAMISU, the REST exploration is developed for the achievement of a high level of automation of its application. In place of the traditional manual blowers (resembling stick vacuum cleaners) swung over the ground manually by operators walking in the explored area, the collection of the samples is performed automatically. The device performing the blowing of air in the filters is pushed into the area to explore at the

CLOSE-IN-DETECTION

Mobile robots are more and more leaving the protected lab environment and entering the unstructured and complex outside world, e.g. for applications such as environmental monitoring. However, recent events like the Tohoku earthquake in Japan, where robots could in theory have helped a lot with disaster relief but were nearly not used at all in practice , have learned that there exists a large discrepancy between robotic technology which is developed in science labs and the use of such technology on the terrain. The rough outside world poses several constraints on the mechanical structure of the robotic system, on the electronics and the control architecture and on the robustness of the autonomous components. Main factors to keep into consideration are [5]:

- Mobility on difficult terrain and different soils
- Resistance to rain and dust
- Capability of working in changing illumination conditions and in direct sunlight
- Capability of dealing with unreliable communication links, requiring autonomous navigation capabilities

The close-in-detection tools (sensors and sensor-carriers) developed or improved in the TIRAMISU project may be consulted on www.fp7-tiramisu.eu)

Several workshops, a.o. organised by the European Network CLAWAR (Climbing and Walking Robots and associated Technologies, now became the CLAWAR Association Ltd) and the IARP (International Advanced Robotics Programme) allowed discussions on the possible R&D activities for introducing robotic systems in demining operations: despite the fact that robots are not (yet) felt today as the most promising solutions, due to their high cost, the use and maintenance difficulties, the varying (daily changing) terrain conditions, etc, efforts will be pursued to improve the experiments developed by the TIRAMISU partners involved in such R&D.

Tele-operated or semi-autonomous sensor-carriers

The robots will need to carry work packages of various sorts. The most important of these will be sensor packages needed for the Close-in-Detection

Sensor systems

The main objective of mine detection is to achieve a high probability of detection rate while maintaining low probability of false alarm. The probability of false alarm rate is directly proportional to the time and cost of demining by a large factor. Hence, it is important to develop more effective detection technology that speed up the detection process, maximize detection reliability and accuracy, reduce false alarm rate, improve the ability to positively discriminate landmines from other buried objects and metallic debris, and enhance safety and protection for de-miners. In addition, there is a need to have simple, flexible and friendly user interaction that allows safe operation without the need for extensive training.
Currently, there is no single sensor technology that has the capability to attain good levels of detection for the available AP mines while having a low false alarm rate under various types of soil, different weather, all types of mines, natural and ground clutters, etc
In TIRAMISU, combination of sensors will be envisaged including Metal detector arrays, Ground Penetrating radars, Chemical Sensors and even Bio-sensors (honeybees)

Robots

From 1997 on to 2012, several robotics prototypes have been designed and proposed by R&D Centres, taking the above mentioned basic requirements into account.
Under the CLAWAR association (from 1997 on to 2005) climbing and walking prototypes have been developed and tested on dummy minefields or on accredited (by the GICHD, the former ITEP (International Test and Evaluation Program) minefields. The following figures summarise:

(1) A first strategy RMA and ISR-UC [8] suggested to start with consisted into the use of a step-by-step motion of a multi-legged electro-pneumatic sliding robot equipped with a 3D scanning device, namely a metal-detector or a combined metal detector, IR sensor and GPR: the robot AMRU-4 as well as the LADERO were designed and demonstrated in 2005 on a dummy minefield laid at the RMA.


AMRU-4 (RMA)


LADERO (ISR-UC)

Figure 7. Sliding robots

(2) The major drawback of the sliding robot lies in the fact that they may not be used on irregular terrains. As a consequence, multi-legged robots have been proposed by some R&D centres as the CSIC

(Agencia Estatal Consejo Superior de Investigaciones Cientificas, Madrid, Spain)[9] or the CHIBA University [10]. Prof Dr Ir M.Armada summarises the advantages of legged robots as such:

- Legged machines only require a finite number of contact points with the ground decreasing the likelihood of stepping on an anti- personal mine.
- After detecting a personal mine, the possibility of the machine for going further is much more bigger than the same for a wheeled or tracked rover (wheels and tracks describe a continuous path).
- The inherent omni-directionality of a legged robot is also a great advantage for changing the steering without forward/backward maneuvers.
- A legged machine can negotiate irregular terrain maintaining the body always levelled. This can be of paramount importance for carrying onboard sensors and equipment that need to be levelled while measuring
- Walking on a slope with the body leveled is an easy task for legged robots without jeopardising the stability .
- Mobility on stairs, over steps and over ditches is one of the main advantages of legged robots. That means they can be used to reach dangerous areas in both structured and unstructured environments
- Legged robots can walk over loose terrain such as sand and legs endowed with proper force sensors can identify the stepped terrain to prevent slippery.
- A legged machine provides additional motions along x-axis, y-axis and z-axis and even body rotations without changing the footprints. So, these motions can be considered as additional degrees-of-freedom of the sensors and equipment onboard the body .

The SILO-6 and DYLEMA multisensorhead (CSIC)

The COMET III (CHIBA)

The AMRU-5 (RMA)

Figure 8: Multi-legged robots

However, building a walking robot requires more expertise than a simple programming. The robot designers must own a compendium of basic skills from fields such as mechanical engineering, electrical engineering, computer science, automatic control and artificial intelligence. The cost, the reparability and the reliability are also factors braking the implementation of such machines in operational conditions.

(3) Without eliminating specific designs, priority is given today to the use of commercially available UGV or remote controlled platforms allowing an easier (and cheaper) transfer of hand-held sensors or hand-held multi-sensor-heads. The best known machine, tested in Croatia, Afghanistan and Egypt is the GRYPHON IV developed by the R&D team lead by S.Hirose [11] and equipped with the ALIS multi-sensor-head designed by the Tohoku University [12]

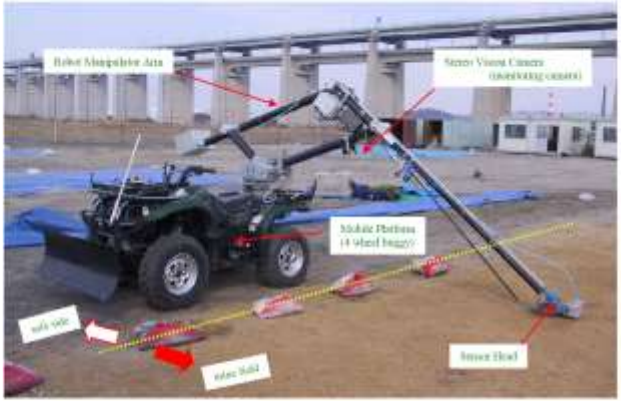

Figure 9. The teleoperated buggy vehicle and weight balanced arm “Gryphon-IV” during field tests at Kagawa. The mobile platform is based on the Yamaha GRIZZLY 660. It can be both manually driven and/or teleoperated. The arm is equipped with a commercial metal detector CEIA MIL-D1, which is presently the most widely used manual mine detector in Afghanistan. A GPR (ground penetrating radar) can also be integrated to the system. This photo illustrates the system performing an automatic scanning of the prepared mine field with uneven ground surface, during the “Test and Evaluation on Mine Detection Sensor Systems (prototype)” promoted by the Japan Science and Technology Agency (JST) in March 16, 2005, at Bannosu Industrial Park, Sakaide City, Kagawa Prefecture, Japan.Left: the ALIS syetm tested in Egypt.

All other robotics platforms, including the TIRAMISU prototypes, didn’t be used in operational conditions, well on dummy minefields and/or in virtual simulations. All robotics systems have to respect the basic requirements defined by the End-users:

- High Mechanical Reliability: robust material and electronics to support high humidity, high temperature, dust, sand, rain, etc.
- Good resistance to accidental explosions: a protection shield could be a solution.
- Easy to use: A simple man-machine interface must be provided in order to allow a non-robotic expert operator to control the robot.
- Easy to repair: A modular construction can help to repair the robot easily and efficiently. The devices more in danger on an accidental explosion should be simple and modular and able to be re-constructed with simple and locally available materials.
- Low cost: In general all the parts should be based in systems spread all over the world. Mechanical parts could be based on very simple designs
- Autonomy: At least half a day of autonomy is required. In electrical robots this can also be accomplished using petrol engine onboard or using tethers for supplying the power from outside the robot. The handle of the tether however can be a great problem to be solved

The following prototypes have been developed and/or will be further implemented in close cooperation with Mine Action Centers and the Project Advisory Board

ISR-TT (ISR-UC) [15]

TRIDEM (RMA-TUI [13]

MDBOT (University of Prishtina [14]

Figure 10. Some protypes in development under TIRAMISU

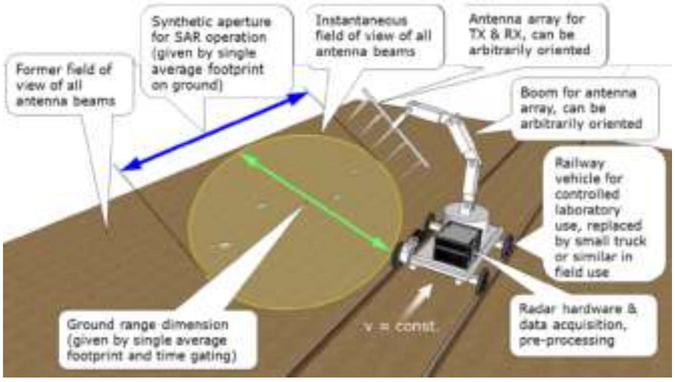

Figure 11. TIRAMI-SAR (DLR)

(4) Most robots are proposed to be used in tele-operated mode, according to the manual demining procedures, namely along a corridor allowing a lateral scanning: this is the case of the GRYPHON and that will be the case with the implementation of the TIRAMI-SAR as illustrated in figure 11. However, a new trend appears, supposing a semi-autonomous navigation in the suspected area assisted by a preliminary scanning of the infested field by a remote piloted aerial platform, a mini unmanned vehicle (RPAS- MAV). This new technique derives from the combination of non-technical survey, technical survey and close-in-detection. Thanks to the pre-localization of suspected explosive devices (cluster munitions laid on the ground, typical bombing remnants, etc resulting from aerial imagery processing (with camera, NIR, FLIR or chemical sensors or even bio-sensors (honeybees tool), the UGV may be moved on a more optimal way towards the suspected devices. The following figures illustrate the current R&D related to the use of combined UGV-RPAS)

UGV with quadcopter onboard (UNICT-Catania [15]

CTDT Airship for hyperspectral data acquisition in Croatia [16]

TeoDOR UGV with quadcopter (RMA [17]

Figure 12. UGV-UAV combination for optimal detection and disposal of explosive devices

ICARUS

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 [5] 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 [5], 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.

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) [22] are very well suited to fulfil 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.

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 [23] (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.

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 [19] 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.

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 [24] 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.

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.

Figure 14. ICARUS demonstration scenarios for heterogeneous robot collaboration in a land scenario (USAR response after an earthquake) and a marine scenario (shipwreck in coastal waters)

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 [25]. 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.

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 [20].

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.

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 [26]. 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.

CONCLUSIONS

Natural and man-made disasters, the presence of visible sub-munitions and UXO (figure 14) and buried landmines still affect a lot of areas over the world and disrupt our society.

Figure 14. Benkovac Test-site in Croatia and UXO targets near the Padjene exploded ammunition[18]

Robotics solutions properly sized with suitable modularized mechanized structure and well adapted to local conditions of un-structured, sometimes unknown terrain can greatly improve the safety and the security of personnel handling these problems, as well as work efficiency, productivity and flexibility. Solving this problem however presents challenges in robotic mechanics and mobility, sensors and sensor fusion, autonomous or semi-autonomous navigation and machine intelligence. The introduction of RPAS also introduce ethics aspects that have to be treated: this fact was underlined by Ms Agnes Marcaillou [2] and will probably lead to an international treaty banning 'robotic weapons'….an evolution to be followed.

ACKNOWLEDGMENT

The research leading to these information and results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 284747 and grant agreement n° 285417.

REFERENCES

[1] Sylvie Brigot-Vilain, International Campaign to Ban Landmines – Cluster Munitions Coalition (ICBL-CMc Executive Director), The OTTAWA convention: the first step towards Humanitarian Disarmament, Colloquium at RMA on March, 28, 2013.
[2] Agnès Marcaillou, UNMAS Director, The OTTAWA convention: the first step towards Humanitarian Disarmament, Colloquium at RMA on March, 28, 2013.
[3] Maki K.Habib (Professor at University of Cairo, IEEE referee, expert in Humanitarian Demining – mechanical assisted mine-clearing), Jun ISHIKAWA (Dr. Eng., Department of Robotics and Mechatronics School of Science and Technology for Future Life Tokyo Denki University), Ioan Doroftei (Expert in Demining Robotics, Technical University of Iasi, Romania), Dr M. O. Tokhi (The University of Sheffield, UK, Expert in Robot Ethics and CLAWAR Trustee), prof dr Ir G.Virk (University of GävleChairman CLAWAR, Ethics and Standardization Robots): FP7-TIRAMISU Project 284747
[4] GICHD Mechanical Demining Equipment Catalogue 2010, GICHD, Geneva, January 2010
[5] Doroftei, D., De Cubber, G., Chintanami, K., "Towards collaborative human and robotic rescue workers", Human Friendly Robotics, 2012.
[6] Dr Maki K.Habib, 'Robotization and Humanitarian Demining' Clawar-task12-report, 2001
[7] Marcin Szczepaniak, Ph.D. Eng.; Wieslaw Jasiński MSc. Proposal for construction of demining machines and trailers for the transport of dangerous goods carried out within the project TIRAMISU (9th IARP WS HUDEM'2012, April , Sibenik, Croatia)
[8]S.Larianova (promAutomation Ltd, Russia), A.T.de Almeida and L.Marques (University of Coimbra): Sensor fusion for an automated landmine detection on a mobile robot, Woodhead Publishing 2011 'Using Robots in Hazardous environments, ISBN 978-1-84569-786, pages 147-184,
[9] M. A. Armada, J. Cobano, E. Garcia and P. Gonzalez de Santos,Industrial Automation Institute-CSIC, 28500 Arganda del Rey, Madrid, Spain: Configuration of a legged robot for humanitarian de-mining activities, 5th IARP WS HUDEM'2005, Tokyo, 21-23 June 2005
[10] K.Nonami, et al.: Development and Control of Mine Detection Robot COMET-II and COMET-III, JSME International Journal, Ser.C, Vol.46, No.3, pp.881-890, 2003
[11] Edwardo F. FUKUSHIMAa*, Paulo DEBENESTa, Yuki TOJO,Kensuke TAKITAa, Marc FREESE, Helmuth RADRICH and Shigeo HIROSE Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8552, JAPAN: Teleoperated Buggy Vehicle and Weight Balanced Arm for Mechanization of Mine Detection and Clearance Tasks, 5th IARP WS HUDEM'2005 proceedings, pages 58-63

[12] Gad EL-QADYa,b* Motoyuki SATOc and Keisuke USHIJIMAa a Kyushu University, Hakozaki,6-10-1, Fukuoka 812-8581, JAPAN b National Research Institute of Astronomy and Geophysics, 11722 Helwan, Cairo, Egypt
c Tohoku University, Center for Northeast Asian studies, 41 Kawauchi, Sendai 980-8576, JAPAN: Mine problem in Egypt: Demand for new technology, 5th IARP WS HUDEM'2005 proceedings, pages 5-8
[13] Prof. Ioan Doroftei, PhD, Ionel Conduraru, PhD Student, Alina-Mirela Conduraru, PhD Student, Prof. Yvan Baudoin (Technical University of Iasi, Romania, RMA):Developments on a wheled mobile robot for Humanitarian demining Clearance (Robotica & Management, 17-2 / 2012)
[14] Arbnor Pajaziti, Ka C Cheok and Xhevahir Bajrami (Faculty of Mechanical Engineering, University of Prishtina, Kosovo; School of Engineering and Computer Science, Oakland University, Rochester, Michigan, U.S.A; Faculty of Mechanical Engineering, Vienna University of Technology):Semi-autonomous mobile robot for mine detection, Proceedings 10th International Symposium HUDEM and 11th IARP WS HUDEM'2013, Sibenik (ISSN 1848-9206), pages 105-108]
[15] L. Cantelli, M. Lo Presti, M. Mangiameli, C.D. Melita, G. Muscato (Dipartimento di Ingegneria Elettrica, Elettronica e dei Sistemi, University of Catania): Autonomous Cooperation Between UAV and UGV to Improve Navigation and Environmental Monitoring in Rough Environments. Proceedings 10th International symposium HUDEM, (ISSN 1848-9206), pages 109-112
[16] Andrija Krtalic, Milan Bajic (Faculty of Geodesy-Zagreb, Croatia, FGUNIZ-CTDT):
Upgrade of the Advanced intelligence decision support system for mine action in project TIRAMISU. Proceedings 10th International symposium HUDEM, ISSN 1848-9206, pages 83-86
[17] H. Balta (RMA), G. De Cubber (RMA), D. Doroftei (RMA), Y. Baudoin (RMA), H. Sahli (VUB): Terrain Traversability Analysis for off-road robots using Time-Of-Flight 3D Sensing : IARP WS RISE-ER 2013, Saint-Petersbourg, October 1-3 2013
[18] Milan Bajić, Tamara Ivelja, Andrija Krtalić, Mile Tomić, Dejan Vuletić (CTDT, FGUNIZ, Croatia):
The multisensor and hyper spectral survey of the UXO around the exploded ammunition depot, of the land mines test site vegetation, Proceedings 10th International symposium HUDEM, ISSN 1848-9206, pages 91-96
[19] K. Berns, K. Kuhnert, C. Armbrust, "Off-road Robotics - An Overview", KI - Künstliche Intelligenz - Springer Berlin / Heidelberg - 109-116, 2011
[20] K. Chintamani, "Augmented reality navigation interfaces improve human performance in end-effector controlled telerobotics" (January 1, 2010). ETD Collection for Wayne State University.
[21] D. Doroftei, G. De Cubber, K. Chintanami, "Towards collaborative human and robotic rescue workers, Human Friendly Robotics, 2012.
[22] D. Hofstetter, F. Giorgetta, E. Baumann, Q. Yang, C. Manz, K. Köhler, "Mid-infrared quantum cascade detectors for applications in spectroscopy an pyrometry", Applied Physics B: Lasers and Optics 100, 100(2), 313-320, 2010.
[23] S. Leutenegger, M. Jabas, and R. Y. Siegwart, "Solar Airplane Conceptual Design and Performance Estimation", Journal of Intelligent and Robotic Systems, Vol. 61, No. 1-4, pp. 545-561
[24] A. Martins, H. Ferreira, C. Almeida, H. Silva, J.M. Almeida, E. Silva, "ROAZ and ROAZ II Autonomous Surface Vehicle Design and Implementation", International Lifesaving Congress 2007, La Coruna, Spain, December, 2007
[25] J.C. Sanchez, "New technologies applied to Carrier Monitoring Software", Whitepaper Integrasys SA, 2002
[26] J Bedkowski, A Maslowski, G De Cubber, "Real time 3D localization and mapping for USAR robotic application", Industrial Robot: An International Journal 39 (5), 464-474, 2012