Search and Retrieval of Human Casualties in Outdoor Environments with Unmanned Ground Systems – System Overview and Lessons Learned from ELROB 2014

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Abstract The European Land Robot Trail (ELROB) is a robot competition running for nearly ten years now. Its focus changes between military and civilian applications every other year. Although the ELROB is now one of the most established competition events in Europe, there have been changes in the tasks over the years. In 2014, for the first time, a search and rescue scenario was provided. This paper addresses this Medical Evacuation (MedEvac) scenario and describes our system design to approach the challenge, especially our innovative control mechanism for the manipulator. Comparing our solution with the other teams' approaches we will show advantages which, finally, enabled us to achieve the first place in this trial.

1 Introduction

Rescuing of a wounded person is an important but also dangerous task not only in military scenarios but also in civil disasters. In any case the rescue of a victim results in high risks for the rescuers themselves or, if these risks are reduced, in an unacceptably long duration until the wounded person can be brought to emergency treatment. Here robots can help not only to locate wounded persons in the first place but also to bring them into safety. Exactly this evacuation task was addressed in ELROB 2014 for the first time. Localization of the wounded person was only a minor part of the scenario because in the organizers' view transporting a wounded person was already novel and a hard enough task to be tackled in a trial.

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Since new things often have a strong attraction, there were nine teams altogether trying to accomplish the so-called MedEvac scenario. As, on the one hand, Fraunhofer FKIE acts as scientific advisor for the ELROB competition and, on the other hand, sent a team inside the competition, this paper will present the design of the scenario as well as a system to solve the task. Whereas FKIE's organizing team and the team participating in ELROB were strictly separated before and during the competition the authors can now combine both insights to present results and some lessons learned.

The remainder of the paper is organised as follows: In section 2 we present current system designs to address medical evacuation tasks in general as well as competitions of particular interest for the Search & Rescue (SAR) community. Section 3 will present the MedEvac scenario in detail, describing the scenario design and its realisation during ELROB. Our approach to the MedEvac scenario, the combination of hardware and software, is described in section 4. The performance of our system, also in comparison to other participants, is the topic of section 5. Finally, we close the paper with lessons learned and some conclusions.

2 Related Work

It is generally a problematic task to compare approaches and methods in the field of outdoor robotics [4]. In the majority of cases results are reported only for a specific robotic system. All tasks are carried out in a static and often specially defined environment, making it hard to compare the outcome with results from other research groups, other approaches, and other robots. As one possible solution, robot competitions have been proposed for benchmarking real robot systems [2]. Of course, the difficulties of repeatability and controlled experimentation remain. In outdoor trials, for instance, weather and lighting conditions can dramatically change even for consecutive runs. Starting positions differ and obstacles are not always accurately placed, as exemplarily mentioned in [1]. The authors also notice that new kinds of problems arise. Participants often tend to exploit rules or create special-purpose solutions related only to a specific trial instead of developing adaptive and flexible approaches.

When looking at the Search & Rescue (SAR) domain the very large field of robotic competitions dramatically decreases. Regarding Urban Search and Rescue (USAR) aspects one of the more sophisticated events is the RoboCup Rescue competition, which is part of the annually organized worldwide RoboCup. However, although very well established this competition is far from working in realistic environments. More real-world related are the ongoing DARPA Robotic Challenge (DRC) which is currently in progress. Looking at Europe, one can find the newly founded EURATHLON and, of course, the European Land Robot Trial (ELROB) with its user-centred tasks and real world scenarios. These four competitions will be described in more detail in the following paragraphs.

The RoboCup Rescue is a special part of the worldwide RoboCup competition. The intention of RoboCup Rescue is to promote research and development in interdisciplinary research themes around robot aided search and rescue. The majority of the teams are built by students. The environment used in the competition is constructed based on standard test methods for emergency response robots developed by the U.S. National Institute of Standards and Technology (NIST). The greatest advantage of these so-called arenas is that they allow repeatable tests in an environment anybody can build [9]. There are color-coded arenas with different levels of difficulty available. In all arenas, the robots have to find simulated victims and generate a map, which helps rescuing personnel to locate and rescue the victims.

The DARPA challenges started with the Grand Challenge in 2004. Initially, the goal was to travel autonomously, first in a desert-like area, later in an urban environment. Especially in the context of USAR the new DARPA Robotics Challenge (DRC) is of relevance. The DRC looks for robots capable of assisting humans in response to natural and man-made disasters. After some preliminary decisions, 16 teams have been elected to participate in the semi-finals in December 2013. Details and results can be found at [16]. The finals will take place in June 2015.

Funded by the European Commission, EURATHLON is an international competition that welcomes university, industry or independent teams from any EU country. EURATHLON provides real-world robotics challenges for outdoor robots in demanding scenarios. The focus of the first EURATHLON competition in 2013 was land robots, and had five scenarios covering a number of the key competencies needed in outdoor disaster response, including mapping the disaster site, searching for objects of potential interest (e.g. survivors), turning off valves (i.e. a gas leak), finding hazardous materials and securing them, and navigating autonomously from one place to another [14]. The focus of EURATHLON 2014 was underwater robots, and EURATHLON 2015 will finally add flying robots. Inspired by the Fukushima accident of 2011, this grand challenge will require cooperating groups of land, sea and flying robots to investigate the scene, collect environmental data, then identify and stabilise critical hazards.

The ELROB trials have been started in 2006 as an annual competition, which alternates its key aspect between military and civilian tasks [12]. In contrast to the DARPA challenges, the teams can choose different scenarios. Among these scenarios are different kinds of reconnaissance and surveillance missions combined with the detection of special objects, or transportation, which can be carried out with a single vehicle or in form of a convoy with at least two vehicles. In the recent years several scenarios from the Search & Rescue domain have been added, e.g. the inspection of partially wrecked urban and semi-urban structures or the search for injured persons [13]. The ELROB 2014 competition and especially the Medical Evacuation (MedEvac) trial are subject of this work and are described in more detail in section 3.

Robotic systems for medical support have been discussed in literature for a couple of years now. Apart from victim transportation, other applications include search and localization of injured persons, direct medical support (e.g. providing water or establishing an audio connection) or even life sign detection [11](e.g. through infrared cameras or pulse measurement). In [6] a Cognitive Task Analysis (CTA) is used to identify requirements and preconditions for using robots in such medical applications. Although in [11] Robin Murphy describes a payload for medical assessment and very limited support for the victim, for most authors the idea of using a robot for helping injured persons is more or less a long-term vision. Only in the recent years a couple of large research projects, e.g. the European ICARUS project [3], address victim search and support from a more practical side.

In the context of medical evacuation and victim transport only very few robot systems have been actually built. In [10] a small platform for use in fire-fighting situations has been developed. It can be thrown into a fire site to gather environmental information, search displaced people, and show them the best way out. Of course, this approach requires that the persons can still move on their own. For several years the US Army has sponsored research in the military aspects of robotic casualty extraction and evacuation but this research mainly produced concepts [5] and did not lead to a working system. Among others the problem of safely picking up an injured person was not even conceptually solved.

Other authors addressed partial movement and manipulation of the body of injured persons [7, 15], e.g. to bring their head into a better position for breathing. This task allows using smaller robots and, thus, lowers the risk of further injuring a victim. Since this task only solves a partial problem in rescuing the person, Iwano et al. also discussed using a group of such smaller robots for victim transportation [7]. In [8] the same group developed a completely different approach. Instead of using an intelligent robot, they addressed the vehicle design first and improved a normal rescue support stretcher system, allowing a single rescuer to pick up and transport a victim even on difficult terrain like stairs.

3 Task Description

Before describing our approach to the ELROB 2014 MedEvac scenario we will briefly introduce the general idea of ELROB and the ELROB 2014 competition from the organizers' point of view. Afterwards, the newly created MedEvac scenario in which unmanned ground systems (UGV) had to rescue a wounded person out of a hazardous environment is described in detail.

3.1 The European Land Robot Trial and the 2014 Event

The organizers see the European Land Robot Trial (ELROB) as an opportunity to provide an overview of the current state of the art in European unmanned systems technology. ELROB enables participants and visitors to get a glance at the latest research and development in the area of outdoor unmanned ground vehicles (UGV). For participants from industry ELROB allows to evaluate their commercial products in realistic scenarios dealing with dangerous and hazardous environments. Additionally, participants from universities and research institutes guarantee that also cutting edge methods in robotics can be seen. This mixed field of participants results in a community creating process bringing together developers and users.

Fig. 1: The MedEvac scenario in an overview: Starting from the marked position on the bottom left corner, the participants have to go to each of the marked way-points and search the area for the dummy. After locating the dummy and acquiring a GPS coordinate of it, the robot is supposed to bring the dummy back to the starting position. The whole scenario takes place in a 150m x 150m area with a distance from the dummies to the controllers tent of about 75m.

ELROB 2014 was hosted by the Warsaw Military University of Technology and co-organized by Fraunhofer FKIE. The tasks have been developed in close co-operation with the potential end users and reflect the up-to-date requirements of military forces as well as civil first-responders. Altogether, participating teams could choose from five scenarios:

- Reconnaissance and surveillance in non-urban environments: A specified target area had to be searched for particular markers passing a number of given way-points.
- Mule: A vehicle had to shuttle between the two camps carrying as much payload as possible. The vehicle had to learn the position of the second camp and the route how to get there by following a human guide (teach-in).
- Reconnoitring of structures: An area of interest with a number of small buildings had to be inspected. The robot had to enter the building, partially using stairs, and search for particular markers.
- Medical evacuation: Two wounded persons were lying at two roughly known positions. A vehicle had to approach these positions, locate the dummy and transport it back to the starting point.
- Reconnaissance and disposal of bombs and explosive devices: An area of interest, indoor and outdoor, had to be explored and searched for suspicious objects.

3.2 The MedEvac Scenario

The rescue of wounded persons is an important yet often difficult task in civil catastrophes as well as in military scenarios. During military operations the retrieval of casualties usually takes place in hostile environments, thus leading to severe dangers for the involved soldiers. The use of robotic vehicles, first, to find injured persons and, second, to autonomously pick them up and transport them back to safe areas obviously is a great improvement (see figure 1).

In the MedEvac scenario, as well as in all other ELROB scenarios, one operator and on technician are allowed during the run. While the operator has only the information he or she gets from the control station (and e.g. no direct line-of-sight) the technician is allowed to follow the robot. Thus the technician is able to perform an emergency stop to prevent the robot from damage or free the robot if it gets stuck. All interventions by the technician were measured and resulted in penalties.

During the scenario the wounded persons were represented by dummies. Depending on what the robot was capable to transport, participants could choose between $10kg$, $35kg$ or $74kg$ dummies. While the $10kg$ dummy was only a black bag, both other dummies were in a human-like shape. Additionally, the dummy had a pull strap or loop for easier transportation. In the scenario two wounded persons were hidden at two roughly known positions (named with P_1 and P_2). The participant had to first approach P_1, search and locate the dummy, and then transport it back to the starting point e.g. by dragging it at the special strap, by pushing it, or by completely lifting it. Afterwards, the same had to be done for the area around P_2.

The environment was characterized as a typical non-urban terrain with obstacles like high grass, ditches, trees and bushes. In the actual scenario the environment appeared as a large grassy area. Most of the grass was waist-high, thus, the organizers decided to cut down some parts to enable participants to use autonomous functions and smaller robots. Nevertheless, one of the two dummies could only be found by entering the high grass area.

In addition to the main task, the rescuing of the wounded persons, participants could gain extra points for additional tasks:

- acquired imagery and exact GPS positions of both dummies,
- transmission of all data to the control station, online or offline after having returned to the starting point,
- transmission of live position and video imagery.

The scenario ended with manoeuvring both imitated wounded persons back to the starting point or with reaching the time limit of 45 minutes. Transferring any result data had to be done within the scenario time.

4 System Description

In this section we describe the idea how to solve the MedEvac task as it is described in section 3. This includes the question 'How to transport the dummy?' as well as technical decisions and the control method for the robot and especially the manipulator. All decisions were made not only having the task in mind, but also with a focus to perform best in that scenario. This includes to respect the score sheet in a way that bonus points should be achieved and aspects which are not relevant for the points system can be postponed.

4.1 Our Scenario Approach

To optimize the scoring three different aspects had to be considered. Firstly, as ELROB always wants to foster autonomy, more points can be achieved with semi-autonomous and autonomous robots than with simple tele-operation. Secondly, the time needed to complete the task is important, and, thirdly, the weight of the dummy that is handled. Additionally there are no penalties for being rude to the dummy. In fact, as this was the first time MedEvac was offered as an ELROB scenario, the possible solutions should not be narrowed by too much restrictions.

Dealing autonomously or semi-autonomously with the scenario was not possible for us because the preparation time between announcement of the scenario and the actual competition was too short. Thus, we had to focus on speed and power of the resulting system. We agreed that the scenario was not solvable without some kind of manipulation. As we have no manipulator able to handle the $74kg$ of the heaviest dummy but a robot which is capable of moving such weights, we realized that the manipulator should be best used to link the wounded person with the robot, and afterwards the robot itself should actually move the dummy. This resulted in a towing approach. The manipulator was used to attach a hook to the gear of the wounded person. This hook was attached with a steel rope to the robot. Thus, after hooking the dummy, the robot was able to tow the dummy back to the starting position.

4.2 The Mobile Platform

Our vehicle is the prototype GARM built by RUAG in Switzerland in collaboration with FKIE's engineers. It is a robot in the $500kg$ class with a long-lasting lithium-ion-battery and a tracked drive. In this class it is one of only few robots that have a closed-loop controller for the engines, which allows sending velocities from the computer to the robot and makes autonomous navigation a lot easier. This is quite unique because most other robots of this size are built solely for tele-operated EOD missions and just let the operators control the power of the engines directly. Usually they are not equipped with any odometry sensors at all. The top speed of our robot is roughly 20 km/h and the possible payload is about $200kg$. The chassis is water-resistant, but should not be submerged completely.

We use a payload box developed by FKIE that is equipped with a 7 degrees-of-freedom (DOF) manipulator taken from a telerob telemax EOD robot. It has a parallel gripper that can be opened and closed. The third joint from the base is a prismatic joint that enables the manipulator to extend the upper arm for about 30 cm. Thus, the manipulator has a range of around 1.7 m. For communication freely available WiFi components where used which are able to cope with distances of up to several hundred metres, so fully sufficient for the described MedEvac scenario. We used standard IEEE 802.11n with flexible channel planning at 2.4 GHz and 5 GHz frequencies.

4.3 Robot Control

The robot control was designed mainly to deal with the task as fast as possible. It consists of three different aspects: fast set-up of the system, easy manipulator control, and robustness against connection failures.

4.3.1 Driving and GUI

As most other research groups we are using the Robot Operating System (ROS) framework. In our solution the robot and the control station are two physically divided systems. This causes problems in ROS if the connection between robot and control station is unreliable. As a solution we use the FKIE Multi-Master extension for ROS, giving us an improved robustness against temporary connection failures. Within the multi-master the existing ROS master is unchanged and executed independently on each robot. To enable the ROS nodes which are registered at different ROS masters to communicate with each other, each node has to be registered at each ROS master. Therefore, the ROS master provides a XML-RPC-interface, so we do not have to change the source code of the ROS master. A so-called sync-node is responsible to register all discovered remote nodes at local ROS masters. Since only the local ROS master is changed by the sync-nodes losses of connection do not result in inconsistent states. To reduce the configuration overhead, a discovery node discovers other discovery nodes by steadily broadcast and received heartbeat messages. The discovery node also monitors the local ROS master and announces the timestamp of last change using heartbeat-messages. So the remote *sync-node* can detect the changes and update theirs synchronization. Additionally, the Multi-Master comes with a graphical user interface for managing launch files, greatly helping us to build a quick set-up system. The code of the ROS Multi-Master is published with BSD license at github and the documentary can be found at [17].

The robot GUI is build of rqt widgets. Beside pictures of the three cameras (manipulator hand and turret; overview camera) we display a map of the area, which displays, for example, the given way-points for the scenario. As we expected an environment very difficult for autonomous driving, we included two kinds of driving control: autonomous driving via way-points set in the map, and a simple joystick control.

4.3.2 Manipulator Control

Although the chosen method to pull the wounded person out of the dangerous area looks simple, it yet results in a difficult manipulation task. The hook has to be safely placed at the gear of the dummy but it is not known in advanced where a suitable strap will be located. Additionally, the exact position of the dummy is unknown.

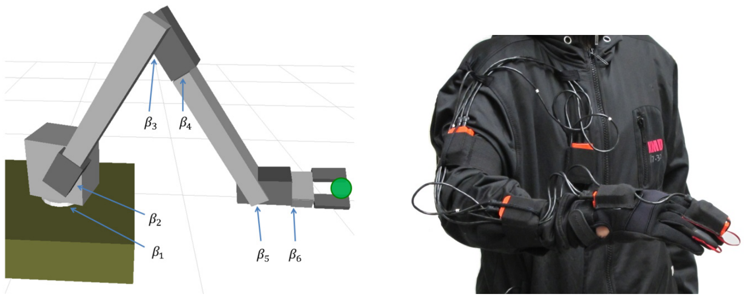

Fig. 2: Directly coupled man-manipulator control. Using several IMUs (right) the operator's movement is measured and transferred to the manipulator (left).

Thus, we decided to solve the manipulation task purely tele-operated. Whereas typical solutions to manipulator tele-operation include at least a joystick and some combination of direct joint control and tool-center-point control, we introduce a novel system for controlling the manipulator directly by the movement of the operator's arm.

The operator is equipped with a jacket in which an inertial measurement unit (IMU) is placed at each part of the arm (see figure 2). By measuring the current orientation of each of those sensors the actual arm position can be calculated. Using also the velocity readings an automatic calibration can be done (see [18]). This enables the operator to wear the jacket during the competition run, access the manipulator control if necessary and switch to other control mechanism without time delay. Additionally, this manipulator control method enables the operator to conduct even complex manipulation tasks in a very intuitive manner, as described in detail in [19].

5 MedEvac at ELROB 2014 – The Competition

5.1 Solutions of Other Competitors

As stated before, the MedEvac scenario was part of the ELROB competition and new things are appealing to people for the first time. Thus, nine out of the twelve teams participating in ELROB 2014 took part in this scenario. Two types of solutions were presented: towing/pulling - as FKIE did - and lifting.

Two of the industry teams, Cobham and ELP, also chose to tow the dummy back to the starting point (see figure 3). As both robots originally are designed for bomb disposal, they are small and not able to move high weights. Although they both managed to pull the dummies back to the starting position in time, they were only able to move the small $10kg$ dummy.

Lifting the dummy obviously has the advantage that it is much more convenient for the wounded person. The University of Oulu and the team Marek from the War-

Fig. 3: Two other competitors using a similar strategy to our approach: towing the dummy back to the starting point. Due to the size of the robots only the $10kg$ dummy (black bag) could be moved.

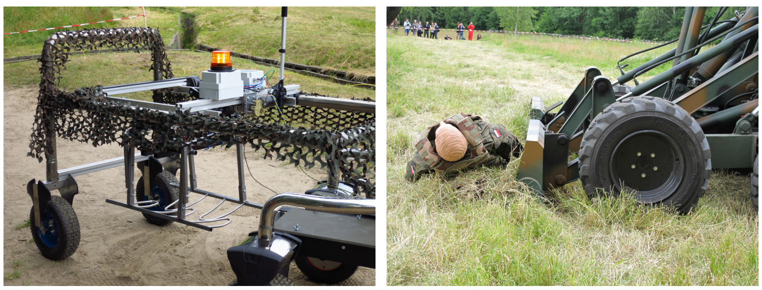

Fig. 4: Two teams presented lifting strategies without using a robot arm. While the University of Oulu constructed a lifting mechanism, team Marek used sheer force in form of a large fork lifter.

saw Military University of Technology (WAT) tried this solution. While Oulu built a pick-up mechanism (see figure 4, left) team Marek performed the task with pure power. They tried to use a fork lifter originally designed for moving around heavy loads (see figure 4, right). Unfortunately, as they had no GPS localization and visualisation they were not able to locate the dummy. Also Oulu could not evaluate their lifting mechanism because the robot was not able to pull the lifting mechanism over the dummy.

Altogether only three teams were capable of locating the dummies and moving them both back to the starting position within the time limit. All three teams had a tele-operated robot. While two teams used small bomb disposal robots and could only move the small $10kg$ dummy, our team successfully moved the heavy ($74kg$) one.

Fig. 5: Left: The FKIE robot at the starting position. Here the dummy had to be brought back to. Right: The robot arriving at the first dummy. From here the manipulation task was to hook up the gear.

5.2 Our Own Run

Our actual run was preponed due to the withdraw of other teams. Thus, preparations had to be done in a hurry, but within less than ten minutes the control station was set up and the robot was ready to enter the scenario (see figure 5, left). First, a dummy in approximately 75m distance had to be retrieved. Due to the high grass, we decided to operate fully tele-operated and drive the robot directly to the given way-point. Although the GARM is capable of driving with up to 20 km/h, we could only go with a maximum speed of 10 km/h as the vibration heavily disturbed the camera image.

The imitated victim was placed in high grass (see figure 5, right), but due to the high viewpoint of the camera (approx. 1.4 meters from ground) the dummy could be located already during the approach and no time was needed to search for it. To gain all extra points a camera picture had to be stored at which the dummy could be clearly seen and also the exact GPS coordinates had to be recorded. This could be done manually because the manipulator control jacket still allowed using keyboard and mouse. Nevertheless, an automatic function would have saved another minute. After acquiring the picture we manoeuvred the robot to the left side of the dummy and started the manipulation task. Standing beside the dummy seemed not to be the best position and the hook was released from the manipulator without being tightly secured. To make sure that the hook held during towing the operator picked up the hook once again and moved it to a better position. This was done without any manual intervention from the technician. The the dummy was towed back to the starting position with a speed of approximately 3.6 km/h.

When arriving back at the starting position the technician removed the hook from the dummy and attached it back to the manipulator. Although this was done at the starting position and was thought to be in accordance to the rules, the judges counted this action as manual intervention. The second dummy was also immediately seen in the video stream but, as it was surrounded by ditches on three sides, the robot could not easily access it. After acquiring the picture and GPS coordinate, the robot moved to the opening in the ditches and was now located directly at the head of the dummy. This position was more beneficial and, thus, the hook could be placed securely at the dummy within less then one minute. Towing the dummy back past the ditches took some time but the total run could be finished within 21 minutes.

5.3 Results

The final scoring sheet ranked our team first with team ELP and Cobham as second respectively third. These teams were the only teams able to finish the task in time. Also all of these three teams presented a tele-operated solution. Our team was the only team with penalty for manual intervention, as the judges counted the removal of the hook from the gear of the dummy as manual intervention even though this happened in the save area, were in a real task medical assistance will wait for the wounded person.

Comparing to the second and third place we reached more points due to the fact that we were able to complete the mission in less than half of the maximum time. ELP as runner-up was able to solve the mission in 28 minutes while Cobham needed more than 34 minutes to transport both dummies to the starting point. Using a robot which was able to tow the $74kg$ dummy equalled out the given penalty for manual intervention. Additionally, it turned out to be important to get the extra points for pictures and GPS positions as this was done by all competitors.

6 Lessons Learned

Competitions are great opportunities to benchmark different systems against each other but they measure always a complete system including hardware, software and the operator. Therefore, some aspects like the robustness of the hardware have a big influence on the overall performance while others, like cutting-edge algorithms, only have an effect if everything else works well. Nevertheless, taking part in a competition is always valuable for the participant to learn interesting lessons about the own system.

One of the main aspects is in our opinion the robustness of the whole system. This includes hardware, software but also an operator who is familiar with the whole system and also the scenario which has to be solved. In the ELROB 2014 MedEvac scenario two participants were not able to present their approaches because of hardware failures. From the retrospective of the last ELROB events this seems to be especially a problem of universities, which are not able to afford expensive hardware platforms. FKIE's cooperation with RUAG resulted in a very robust and sophisticated platform in a robot class (up to $500kg$) which is not really supported by the industry at the moment. Additionally, we use ROS together with the FKIE multi-master extension, a technically mature solution which comes with a graphical user interface for easier system launch management. Especially this graphical user interface results in a robust and fast way to start a complex system with many different software components (ROS nodes).

Our scenario solution, to tow the dummy out of the dangerous area, was a good decision regarding the used scoring system. Nevertheless, in real operation a method has to be found to move a wounded person much gentler. Even if some of the attending relief unit members told us, that there is nothing worse than leaving wounded persons where they are, we expect serious additional injuries by towing the wounded persons over other surfaces than the grass in this scenario.

In our view the novel direct control method for the manipulation task made the real difference to the other teams. Placing the hook at the gear of the dummies was not an easy task, which took a considerable amount of time even for the trained operators of the commercial teams. Having gained a seven minute margin over the other competitors indicates that our control method is feasible for complex tele-operated manipulation with only camera pictures available. It also showed how valuable assistance functions are for the operator in stressful and complex missions. While having such assistance functions for the main tasks (steering the system, controlling the robot and the manipulator), the lack of such automatisms for the bonus tasks (acquiring pictures and GPS coordinates of the victims) was a burden for the operator. The bonus tasks had to be done manually using a lot of different tools and outside the main control architecture. This required a lot of additional concentration and therefore was quite error-prone.

In summary, the authors believe that a successful robot for a competition has to be designed in an easy-to-use way, including the robustness of the hardware, a fast set-up of the system and intelligent assistance functions to reduce the operator's workload. Altogether such a design reduces the error-proneness of the system and increases the chance to present what is unique in your system during the one-shot chance in such a competition.

7 Conclusion

Search and retrieval of human casualties in outdoor environments with unmanned ground systems or, in short, MedEvac was a new and successful scenario in ELROB 2014. Nine teams tried to compete and presented different approaches. Of those nine teams three were able to solve the task. All of those teams used a towing technique to move the simulated wounded person back to a medical care point. Here the fact that there were no penalties for a rough handling of the dummies influenced the solutions. More realistic requirements regarding the victim care will make the scenario more demanding, maybe already in the next ELROB 2016.

Our focus on a robust system together with an intuitive control for the demanding manipulator task not only resulted in winning the scenario but also gave us the special jury award for the "best scientific solution".

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