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An innovative pick-up and transport robot system for casualty evacuation

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Abstract— **This paper addresses the search and rescue scenario Casualty Evacuation (CasEvac) at the European Land Robot Trial (ELROB). A disaster response robot can be sent into areas to rescue victims where it is too dangerous for human rescue due to environmental issues like the danger of collapse or radioactivity. If injured persons are no longer able to move, the robot must be able to rescue them from the danger zone. This paper addresses this scenario and describes our system design, the manipulator tool and the innovative control mechanism for transporting victims. The experiment was tested at the competition and compared with other solutions from the participating teams and currently implemented developments.**

I. Introduction

The ELROB competition is a well-established outdoor robotic competition in Europe with the aim to evaluate and test the capabilities of robotic systems in realistic indoor and outdoor emergency-response scenarios. The trials are divided into several categories and also differ in their areas of responsibility. The motivation of our team was to participate in search and retrieval of human casualties in outdoor environments. The environment has different conditions of terrain, gravel roads, ditches, grassland, numerous bushes and trees, water, paths, fences and other obstacles.

The initial situation was that wounded persons were lying at two roughly known positions. A robot should first approach and locate the nearest person and then bring them back to the starting point. Then the same should be done for the search area around the second injured person. There may be dynamic and static obstacles, dead ends, blockages and narrow passages along the way. It is also to be expected that fences, barriers or any kind of blockages and "negative" obstacles such as ditches could occur. The aim was for the teams to obtain a section of a digital map with two UTM coordinates of the injured persons. In the environment of these points a dummy person (170cm length and a weight of 70kg) with a pull strap or loop for easier transportation has to be found. Each participating team had to report the collected data online or offline to the control station after they returned to the starting point. Additionally they have to transmit a live stream of the mission and exact GPS position of both bodies and the robot system. The mission time of each run was about 30 minutes and the scenario ended when the teams found both victims and were brought back to the starting point or the time limit was reached.

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Fig. 1. RTE-robot a tracked search and rescue robot with a light robot arm, a pick-up and transport module.

A key feature of our work is that we have managed to rescue, pick up and transport people using a 6-DOF robotic arm with a payload of 2 kg. To summarize, our key contributions are:

- To equip a robust chain-driven robot platform with modules for the transport of injured persons;
- A novel method for casualty evacuation with a lightweight robot arm;
- Experimental results validating the casualty evacuation system on a real robot and new insights in evacuation strategy that may impact future solution methods and designs.

II. Related Work

[1] aims to provide an overview of the current state of the art in ground and aerial robots, as well as human-robot control interfaces, with regard to the needs of first responders and disaster response. A comprehensive review and analysis of various robot systems for search, extraction, evacuation, and medical field treatment applications is presented in [2]. Murphy et al. provides an overview and discusses prerequisites, requirements and consequences of using robots for such a role in casualty evacution [3]. A detailed overview of victim localisation, transportation solutions and lessons learned in previous ELROB trials can be found in [4]. A cooperative search and rescue exercise in which an unmanned ground vehicle (UGV) was tested by a military rescue team for the extraction and evacuation

Fig. 2. **(a)** Telerob with Telemax Evo Plus, **(b)** Oulu Robotics Team with M6WD and Kinova arm, **(c)** ELP with Spot Mini

of a casualty from an unsafe man-made disaster area [5]. Charles River Analytics' BRACE[1] project simulates platforms approaching a casualty before working together to bring them to safety. Tokyo Fire Department's Rescue Robot (RoboCue) is designed to locate and safely retrieve victims from disaster sites–specifically bomb sites [6]. Saputra et al. [7] propose ResQbot and with [8] ResQbot 2.0, a novel design for a mobile rescue robot used for casualty extraction. With the BEAR project [9] the US Army Telemedicine and Advanced Technology Research Center (TATRC) and the Defense Advanced Research Projects Agency (DARPA) are collaborating to investigate research to conduct casualty evacuation missions.

Companies such as Telerob or Brokk, which produce versatile robots that can handle large inclines and obstacles or for all kinds of decommissioning work in nuclear power plants, are also involved in rescue robotics [10], [11]. They also investigates research in a Virtual Learning Environment that simulates the collaboration between a construction robot and worker [12] which has synergies with CasEvac missions. Iwano et al. propose solutions for a rescue stretcher system [13] and also with stair climbing capabilities [14].

Many application-oriented robotics competitions, such as the RoboCup Rescue Major League, ELROB or the DARPA Robotic Challenge (DRC) are often used as the benchmarking method for field robotics systems [15], as they allow an objective performance evaluation and give an overview of the different robot systems. Since ELROB was held and the "Search and Rescue (SAR) / MedEvac" and "Search and Rescue (SAR) / CasEvac" scenarios were introduced, many innovative solutions and approaches for the rescue and transport of injured persons have been presented. In 2022 we and the teams in Fig. 2 participated in the CasEvac event, which were all teleoperated.

What the robots in Fig. 2 all had in common was that the injured persons were previously grabbed with a robot arm or by a rope and were then pulled along. However, it should also be noted that the CasEvac exercise was simplified in that the simulated victims each had a sling, which makes it easier to grab a loop or hook on with a carabiner.

[1]https://cra.com/projects/brace/

III. Problem Statement: Casualty Evacuation with a Lightweight Manipulator

Our overall goal in this work is to find injured people using GPS data, collect the victims with a new rescue module and transport them to a safe location; a problem we call *advanced casualty evacuation*. The difficulty with such applications is the very complex handling of a person (weight 70-100 kg). In contrast to [6] and other already implemented prototypes, we use a lightweight arm (payload 1.5 kg) with the robotic platform and have thus found a mechanical solution for the overall casualty evacuation.

IV. Casualty Evacuation Strategy and Robot Concept

Search and rescue of the wounded is an important but often difficult task in civil disaster situations. During operations, casualty recovery (CasEvac) usually takes place in hostile environments, resulting in significant hazards for the first responders involved. The use of robotic vehicles that firstly detect injured people and secondly pick them up independently and bring them back to safe areas would of course be a great improvement.

A. Mission Plan

Since we do not have a manipulator that can handle the 70 kg of the heaviest dummy, but a robot that is capable of moving such weights, we realised that the manipulator would best be used to connect the injured person to the robot, and the robot itself would then move the dummy to the starting point. The strategy and procedure, as well as what equipment was used, is shown in Fig. 5.

B. RTE-Robot

The tracked vehicle is a multi-functional robotic platform that can be adapted to the requirements of the fire brigades and the applications to be performed. The main dimensions of the robot without modules are (L=1068; W=798; H=360)mm. The payload of the robot is up to 650 kg with a tare weight of about 350 kg. There are two quick coupling systems on the tracked vehicle, which can take any type of payload as an interface and thus significantly accelerate the changing of the superstructure modules.

C. Manipulator and Gripper System

The main task of the 6-DoF and gripper system is to establish the connection between the robot and the injured person. It should be noted, that the simulated victims were each equipped with a sling and this provided a suitable pick-up opportunity. This system consists of the following parts: the carabiner, rope, 3d printed gripper, cable ties and a Velcro surface. The gripper system should provide a method for safe hooking and releasing of the person and should be visible through the camera system. Furthermore, the entire system must be modular in terms of quick exchange. Hence there

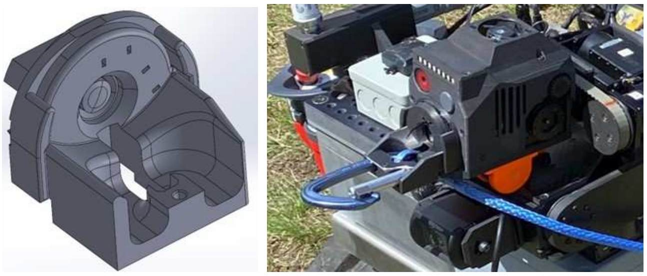

Fig. 3. Robot Manipulator with modified gripper

was a cavity for the carabiner and the rope to fit perfectly into the gripper, see Fig. 3. Field tests were carried out during the days of the competition and it became apparent that some improvements were needed. One of them was to mount the gripper to the head with Velcro and a cable tie. This solution provided a great connection between the head of the robot and the gripper. Furthermore, it had enough strength to hook the carabiner to the person.

D. Rope Guide System

Due to the fact, that the robot has to clip in the hook with the robot arm, which is placed on the front end of the robot but the ramp where the victim should lie during transport is placed on the back end of the robot, the robot has to do a 180° turn after successful hooking. This maneuver can be extremely dangerous for the sensible equipment, like sensors and antennas, which are placed on the robot. If the cable would get jammed somewhere at the robot during the rotation sensors or antennas could be torn off or broken off. A solution is to guide the cable over the sensible components of the robot. Therefore it needs a special rack over the ramp. A second requirement for the rope guide is the maximum load it can carry. We calculated the victim for the competition with a weight of 80kg. As a goal we set a maximum load of 100kg. To proof the functionality of the rope guide before the production we built a prototype of wood in some workshops at the University. With some tests we proofed, if:

- the rope can slide from the front-end to the back-end without jamming;
- the construction can carry heavy loads;
- enough space for victims between rope guide and ramp.

E. Winch Device

The cable winch must have a pulling force of at least 100 kg. To improve flexibility, we decided to use a nylon cable instead of a steel cable. The specifications for the winch are in Table I. In all experiments we only used the first layer of rope, which was sufficient to pick up the victims.

F. Transport and Pick-up Module

The task is to design, construct and manufacture a transport device for an injured person that is mounted on the RTE platform. Furthermore, a concept must be developed that enables a person to be brought onto the device from any type of lying position on the floor. Therefore, the platform

TABLE I
LIFTING AND ROPE CAPACITY PER LAYER:

Rope layer	1	2	3
Lifting force [kg]	400	350	300
Rope capacity [m]	5.3	11.3	14
Speed [m/min]	3.9	4.1	4.3
Current [A]	25	28	30

must be constructed in two parts, so that one part can be lowered to the ground in whatever form. It should also be noted that when retracted, the robot can be maneuvered as easily as possible. One person means the platform should have a size of approx. 180 cm x 60 cm and be able to bear a payload of approx. 100 kg. A tilting device was then developed, with the disadvantage that it cannot be folded in completely due to the cable guide and thus the view (camera position) and maneuverability are more restricted. The ramp is rotatably mounted and is driven by the planned gear motor via a two-stage chain transmission, see Fig. 4.

Due to the resulting high torque in the bearing point of the ramp, the motor is relieved with a spring release system. This also ensures that when transporting a load, the ramp does not approach the ground by itself. Since the ramp is rotatably mounted, the length of the ramp (approx. 700 mm) generates a large torque on it, which the planned engine would never be able to handle. In addition, the engine speed is much too high. A cheap, easy-to-split gear-like transmission component is needed. This results in a two-stage chain transmission as sufficient. The motor torque is sufficient and the speed is reduced, making it easy to control the ramp.

G. System Architecture

Fig. 6 describes interoperability and interfaces between different components. The system is controlled by the operating PC via WIFI (5 GHz). The electronic control boards and the video server are connected to a 10 port ethernet switch. The video server receives four camera signals (CAM 1 to 4) from the camera switch PCB (Printed Circuit Board). The camera switch is supplied with 24V and is connected

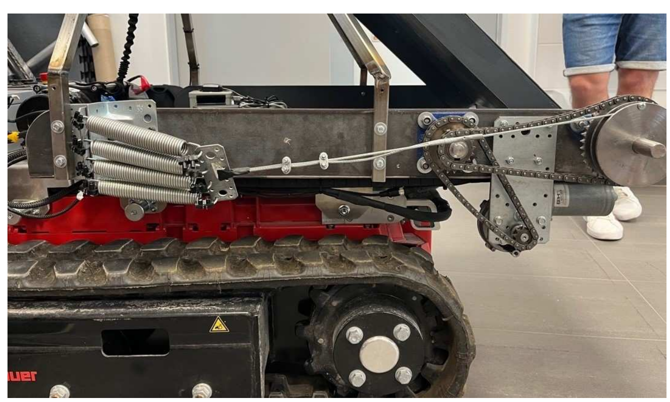

Fig. 4. Gear motor with chain transmission for tilting the ramp

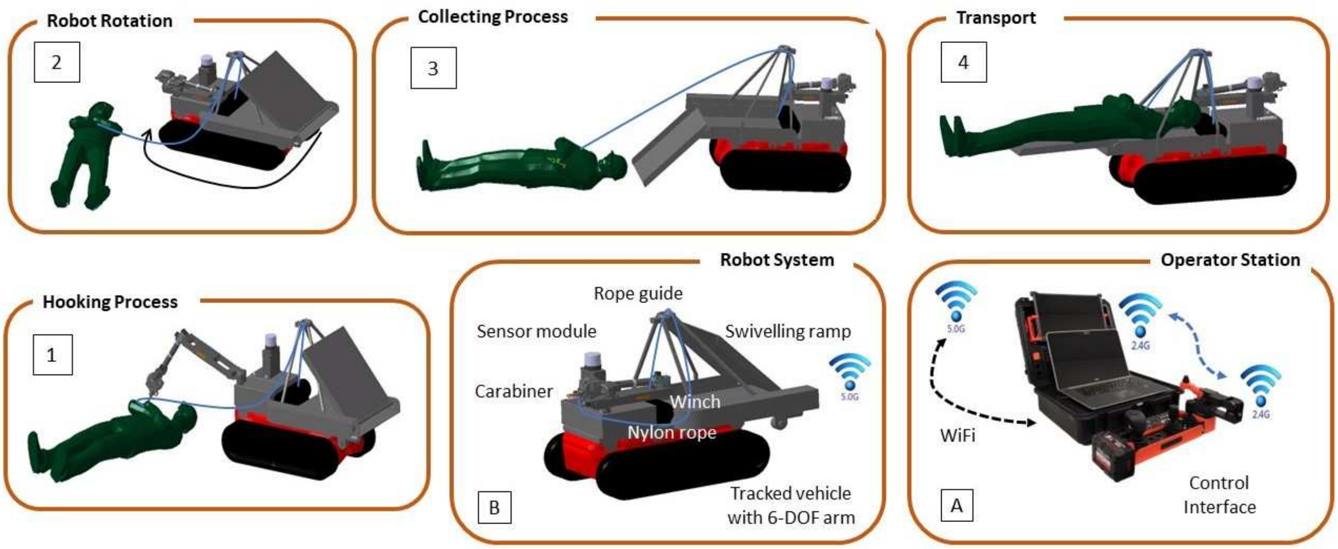

Fig. 5. **Casualty Evacuation Strategy and Robot Concept:** Point **(A)** and **(B)** shows the overall robot system and equipment. Please see main text for details. Our field experiment involved 4 different tasks: **(1)** Hooking Process: The carabiner is hooked onto the chest strap with the robot arm, which means that the rope is also attached to the person. Once the hooking process has been completed, the arm is moved vertically and the carabiner, which has only been attached to the carabiner holder with thin cable ties, will fall out of its anchorage in the process.; **(2)** Robot Rotation: After successful hooking, the robot must be turned 180° to the injured person on the spot. This process is very difficult to implement, especially in the terrain and in narrow passages, whereby one should have a very good all-round view.; **(3)** Collecting Process: After the rotation movement, the ramp must be lowered. The winch and the rope guide can be used to pull the person onto the transport support from any position.; **(4)** Transport: Before starting the transport, the ramp must be lifted up again so that the support surface is increased and the person is in a comfortable horizontal position.

to the main control via CAN and up to eight cameras on the robot. The operator can use the camera switch to switch between the four cameras on the gripper and the four cameras for driving the robot. The heart is the main control that controls the tilt motor, the cable winch, the robot's gripper, the camera switch and of course the robot itself. In order to supply all the individual parts, +48V VDC is tapped from the robot's battery and converted to 24V using a DC/DC converter. The supply board has the task of supplying power to the main control, the camera switch and the gripper which can be stopped by an emergency button. Furthermore, the modular sensor module [16] and the embedded PC (NVIDIA Jetson Xavier) are permanently supplied with 24V and are not affected by the emergency stop, so that measurement data can still be recorded.

H. GPS module

The used GPS receiver is a whadda/velleman VMA430 GPS module U-BLOX NEO-7M for ARDUINO®, which is utilizing an ublox NEO-7M-0 GNSS module. It is powered via the 5V DC onboard voltage supply of the Arduino UNO and transmits data over a 2-wire serial bus. Additionally, there is an Antenna attached to the GPS Module for increased accuracy, which is mounted directly on top of the system enclosure. For data transmission between the GPS module and the micro-controller a 2-wire serial connection was used. For communication, the micro-controller was running the manufacturers provided library and cyclically polling in an interval of 100 µs. To transmit the gathered data from the robot to the PC, an Arduino UNO with an external ethernet shield is used (Iduino ST1044 Ethernet Shield with Micro-SD card reader). A UDP communication is used in the trials with the implementation of a simple request-response model. As detailed in cyclic polling of the PC the cycle is introduced by the web browser's request to the webserver,

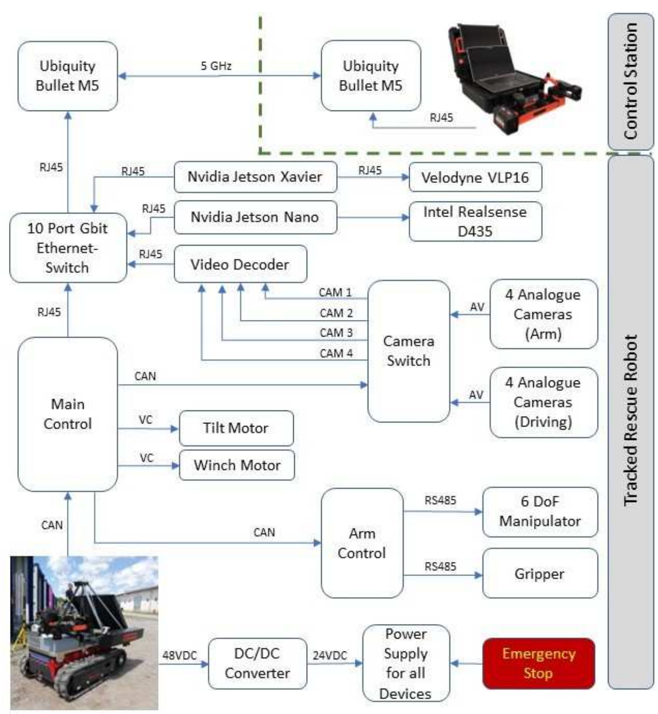

Fig. 6. System overview of the tracked rescue system with the ELROB-specific casualty evacuation modul.

which triggers the request to the micro-controller's ethernet shield. The PC sends a UDP message to the defined IP and port of the micro-controller's ethernet shield which replies with the information to the IP and port that sent the request. No special messages have been determined, as all the data processing is executed by the PC. In further reiterations of the system, a handshake model would be appropriate, as with increasing distance between the robot and the operating station the bandwidth of the connection plummets and packages often get lost.

I. Control Unit

The communication unit and operating unit consists of a PELI case the size of a hand luggage with a laptop and additional screen for visualising the sensor data. The operating unit consists of several levers and control paddles for operating the robot platform and a mechanical twin for controlling the 6-axis manipulator arm.

V. Experimental Results

When navigating outdoors with a robot, you can orientate yourself very well with the cameras, as long as there are also specific points or areas such as gravel roads and trees. Each camera has its own limited field of view (FOV) and if there are few differences in the environment, it can mean that the operator loses orientation when the camera is only moving. This experience was also gained during the field test, where the GPS positions of the robot and the target position were very helpful, see Fig. 7. To display positions as dots over the aerial picture a HTML element called canvas was used. Together with a CSS stylesheet, which allowed to determine the layer and henceforth the order of each individual element.

To distinct between markers, the actual present robot position was marked with a red dot and the points of interests, or waypoints as in this case were displayed in blue and orange, see Fig. 5. To make them more visually interesting a black circle was around them and the points of interest were labelled with P1 and P2. On the top right corner of Fig. 5, the current time was displayed as well as the robot's current position. The markers positions were displayed on the right-hand side of the map. In order to reconstruct certain paths the robot took, the path function was implemented. The path function logs the present position of the robot with every refreshing cycle and adds it as a black dot to the map. Firstly, the path view was only available in the */path* branch of the visualization but was also implemented into the live view branch to assist the operator in finding the way back.

Additional to the path data, which is saved automatically, certain points can be saved additionally in a separate text-file and will be highlighted, and the values displayed in the path view. Another essential finding is the exact positioning of the cameras. In addition to the driving and manipulator cameras, it is important to pay attention to where additional cameras are installed, especially for the recording and transport of the injured person. The tilt mechanism in particular did not make it easy to find the right camera positions.

Fig. 7. GPS visualisation, rope guide, casualty evacuation and transport

The ring on top was realized with four big pipe elbows which are welded together. The final construction is shown in Fig. 7. The entire construction was bolted to the ramp. This means that the rope guide can be removed for tasks in which it is not needed or would interfere. During the loading and transport process at the contest, our solution for rope guidance performed very well and there were no problems.

For the rescue process few things should be considered that the person is pulled onto the platform via one side of the ramp with a cable winch. It would be best that the person's head rests on the fixed part of the ramp. The feet that are still "hanging" over the ramp in the direction of the ground are lifted off the ground by the "folding up" of the ramp and the person thus comes to rest on the robot in an almost horizontal position. The process seems relatively simple, but due to the weight of the person and the ramp itself, the folding mechanism must meet certain requirements.

VI. Discussion and Future Work

The field tests in Fig. 7 show that the robot system is very capable of transporting heavy loads. By using a modular sensor system and a lightweight robotic arm [16], the robot is able to precisely locate and pick up the people. The mechanism for hooking, picking up and transporting people has proven to be very innovative in the field tests and also in the competition. The team was awarded with the *"Young Roboticist Award"* by the organisation, showing that such developments need to be further encouraged. The new robot concept showed great interest among those present and also stands out from previous and current developments. The first prototype of the evacuation and transport of injured persons was described in the previous chapters. We hope that this work will draw more attention to assistive technologies and their use in robotics, especially for outdoor applications. Certainly there are still a number of unsolved problems that need to be addressed, e.g.:

Swivelling ramp. We have also seen in the tests that the concept also has disadvantages. The tilting mechanism obscures the all-round view while driving and the length dimension is also significantly increased. The robot length then has disadvantages as soon as you have to navigate in narrow passages. This is where further considerations on the design of the platform begin. Fig. 8 shows a first CAD model where the ramp is first moved horizontally on the rails by a given drive. The rails have a downward curve at the end. The guides (bearings) of the moving ramp naturally follow the curvature of the guide and it happens that the ramp also moves downwards at the same time on the last 150 mm of the horizontal movement. As soon as the person stands on the ramp, the ramp "moves" back these 150 mm and is thus in a horizontal position. Another platform will essentially consist of two steel tubs connected by a rail system. Due to the rope guide mounted above it, the ramp must be fully retractable and able to accommodate the size of the base plate. Fig.8 shows a first CAD model where the ramp is first moved horizontally on the rails by a given drive. The rails have a downward curve at the end. The guides (bearings) of the moving ramp naturally follow the curvature of the guide and it happens that the ramp also moves downwards at the same time on the last 150 mm of the horizontal movement. As soon as the person stands on the ramp, the ramp "moves" back these 150 mm and is thus in a horizontal position.

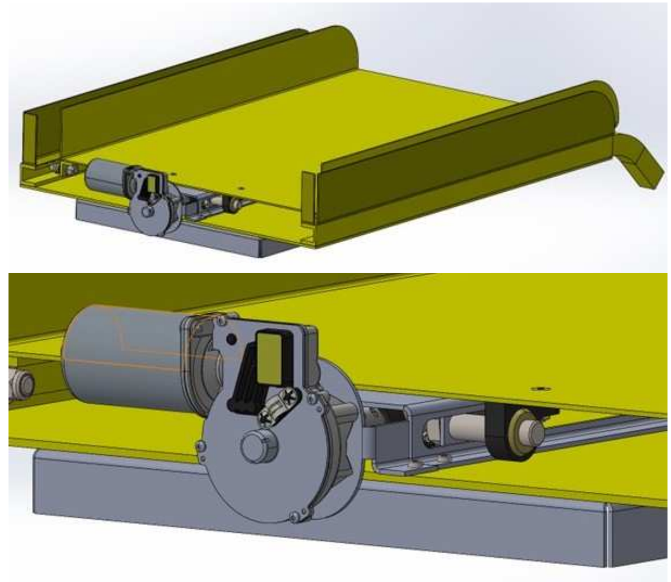

Fig. 8. New prototype of ramp construction

Sustainability Transformation. Digitization is also not keeping the fire brigades and rescue agencies away, and new functions and tasks are emerging as to how such a system can be deployed and used to support the emergency services. The aim is to further improve the health and safety of the emergency services and to support them with new types of assistance systems for dangerous, difficult or particularly strenuous tasks.

Human-Robot-Interaction. HRI, data visualization in a harsh environment and the combination of virtual reality with camera data [17] for an intuitive teleoperation are the key-features and next steps. A comprehensive investigation with corresponding experiments and possible controllers has not yet been completed.

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