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Experimental Validation of a Robotic Stretcher for Casualty Evacuation in a Man-Made Disaster Exercise

Anthony Mandow, Javier Serón, Francisco Pastor, and Alfonso García-Cerezo[1]

***Abstract*— This paper describes a cooperative search and rescue exercise where an unmanned ground vehicle (UGV) is used by a military rescue team for extraction and evacuation of a casualty from an unsafe man-made disaster area. This experimental validation was performed within a full-scale emergency response exercise organized on June 2019 by the Chair of Safety, Emergencies and Disasters at Universidad de Málaga (Spain). With this purpose, we adapted the skid-steer Rambler robot to carry a stretcher with appropriate roll-in and locking mechanisms. The mission consisted of two phases: first, extraction from the hot zone was performed with remote teleoperation using a dummy; second, casualty evacuation (CASEVAC) to an aeromedical evacuation point was done with sightline teleoperation moving an actual volunteer. The realistic one-shot exercise was performed by actual rescue personnel with no previous experience with the robotic system. The paper shares insight and lessons learned from this concept validation experience.**

Keywords - Disaster robotics; Search and rescue robots; Unmanned Ground Vehicles; Casualty evacuation.

I. Introduction

Using unmanned ground vehicles (UGV) for victim extraction from unsafe areas in natural and man-made disasters is a key application of rescue robotics [1]. The support of robotic systems for casualty extraction and casualty evacuation (CASEVAC) can increase the operational flexibility, act as force multiplier in high demand situations, and reduce risks for first responders in both civil and military scenarios.

However, not so many works have addressed casualty evacuation and extraction [2]. Furthermore, existing solutions pose interesting research challenges, as analyzed in a recent review by Williams *et al.* [3]. Some researchers have tackled manipulation aspects of casualty extraction, such as placing the hook to tow the victim to a safe area [2] or lifting the person with a dual arm [4]. However, manipulation of a casualty can cause additional damage, such as neck or spinal chord injuries. Thus, other works have focused on simpler and safer procedures based on stretchers.

Large robotic multipurpose equipment transport platforms developed for military applications have offered the possibility of carrying multiple stretchers for casualty evacuation [3]. On the other hand, the works of Iwano *et al.* [5] [6] aimed at helping first responders to extract and move casualties with a stretcher-like robot platform with a conveyor system, a concept that has been extended in other works [7].

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[1]Universidad de Málaga, Robotics and Mechatronics Group, Andalucía Tech, 29071 Málaga, Spain. amandow@uma.es, ajgarcia@uma.es

Fig. 1. All-terrain Rambler robot with the adapted detachable onboard stretcher.

In this work, our major goal was to test a robotic concept that can be accepted and integrated in a straightforward way into the procedures of actual rescue personnel. Thus, we do not address casualty body manipulation. Instead, we adapted a highly maneuverable all-terrain UGV (see Fig. 1) so that rescuers could easily attach the stretcher for safe transportation of the casualty in an unstructured disaster environment. To the best of our knowledge, this is the first robotics research work that documents and discusses the use of a stretcher robotic system in a casualty extraction and evacuation scenario performed by actual first-rescuers in a realistic exercise without previous training.

The remaining of the paper is organized as follows. Section II provides context and the objective of the exercise. Section III describes the robotic system. Section IV discusses how the exercise was developed and offers some insight and lessons learned. Finally, Section V is for the conclusions.

II. Evacuation Mission Overview

The UGV casualty extraction and evacuation scenario was part of a large-scale disaster response exercise conducted in Málaga (Spain) on June 6, 2019. The exercise involved a series of scenarios corresponding to a man-made disaster and was organized by the Chair of Safety, Emergencies and Disasters at Universidad de Málaga (UMA).

An aerial view of the exercise area with a layout of the robotic stretcher mission is shown in Fig. 2. The first

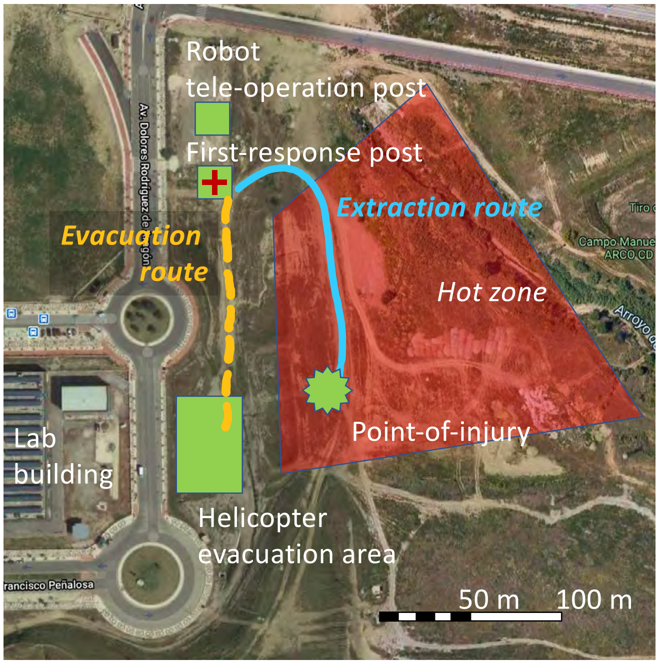


Fig. 2. Casualty extraction and evacuation scenario layout over an aerial view of the disaster response exercise site [8].

response post and the robot teleoperation and control post were in a command tent area along with other organizations participating in different scenarios. This command post area was also the starting and finishing point for the UGV routes. In the simulated scenario, an explosion caused a casualty in the point-of-injury, which was located within an unsafe hot zone with continuing attacks.

The exercise site is a dedicated $90000\mathrm{m}^2$ outdoor experimental area within the UMA campus. This area includes rubble mounds, vegetation, crashed vehicles, and partially buried pipes. This outdoor area is an unstructured natural environment with different terrain altitudes. For instance, the point-of-injury is about eight meters above the helicopter evacuation area.

The robotic stretcher was tested in a cooperative training exercise with a combat medical unit of the Spanish Army (Tercio "Alejandro Farnesio" 4^o, of the Spanish Legion). The exercise consisted on two phases:

1) Casualty extraction: The UGV reaches the point-of-injury within the hot zone and moves the victim to a safe location (the first response post) where initial medical care can be provided
2) Casualty evacuation: After the helicopter evacuation is approved, the UGV moves the victim to the helicopter evacuation area for transport to a medical treatment facility.

III. Robotic Stretcher System

In this section, we present the robotic system consisting of the Rambler UGV and its detachable stretcher. The goal was to adapt the Rambler robot so that a commercial stretcher could be mounted and unmounted in a simple and

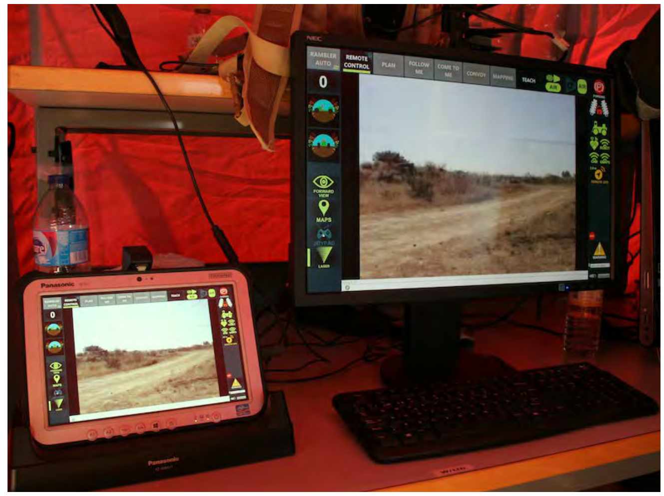


Fig. 3. Teleoperation post (right) and portable teleoperation tablet (left). The photograph was taken in the tent of the robot command post.

straightforward way. Furthermore, a crucial requirement was that the stretcher could be safely fastened and locked onto the all-terrain UGV so that it could be safely used to carry a human volunteer.

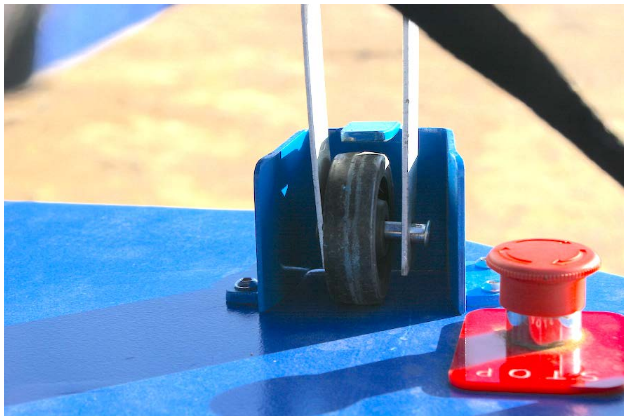
A. Rambler robot

Rambler (see Fig. 1) is an electric off-road unmanned ground vehicle (UGV) driven by four brushless hub motors with independent controllers. This UGV is powered by 64 lithium iron Li-Fe batteries forming 16 cells with their corresponding charge, discharge, and temperature monitoring controller. It has independent pneumatic active suspension provided by double-acting cylinders and pressure controllers, two for each cylinder. Besides, a pneumatic compressor supplies the required pressure. Rambler's sensors include an inertial measurement unit (IMU), GPS with differential corrections, a pan-tilt-zoom (PTZ) camera, a LIDAR and temperature, humidity and concentration sensors of different gases. Rambler weights $460\mathrm{kg}$ with dimensions $1.6\mathrm{m}$ (l) $\times$ $1.2\mathrm{m}$ (w) $\times$ $0{,}66\mathrm{m}$ (h) and has a payload of $300\mathrm{kg}$.

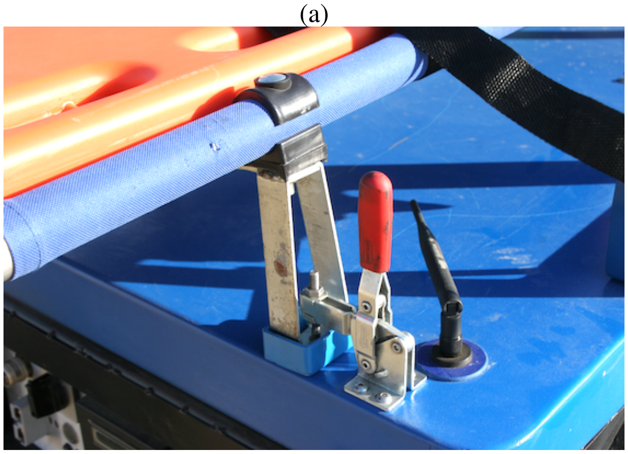
B. Teleoperation

The Rambler robot was teleoperated by one of our engineering team members. In particular, two teleoperation interfaces have been used, as seen in Fig. 3:

- A remote robot teleoperation post (in the command tent area) was used for the extraction phase. Visual feedback is provided by the images streamed from the onboard camera. Besides, GPS and IMU data provide information about the robot status, and position estimation is overlaid onto a map of the area. Communication between Rambler and the teleoperation post was done through bonding. This method consists of using the 4G network with two different suppliers; in this case, we used the two leaders in Spain: Movistar and Vodafone. Particularly, we had a Peplink Balance 310X router with Ethernet connection in our lab building was used to manage the bonding between two Peplink MAX HD2



(a)



(b)

Fig. 4. Stretcher fixing details: a) front end wheel brackets; b) rear manual locking mechanism.

4G LTE routers: one onboard router for the robot and the other for the teleoperation station. This kind of communication allows more than enough bandwidth and a very low connection loss rate since the information is sent with redundancy by both operators.

- A portable teleoperation device provided a graphical interface similar to the teleoperation post. This device was a tactile tablet held by a rigid support designed to be attached to a backpack containing batteries and communication systems (including the teleoperation router). With free hands, the operator can also use a standard XBOX 360 console joystick to control the robot motion. The portable interface was used for safer line-of-sight operation in the evacuation phase because the robot carried an actual person.

C. Stretcher system

We used a commercial stretcher with two wheels on the front end and two legs on the back, as seen in Fig 4. In particular, we chose a foldable stretcher because its reduced size allowed inserting it loaded into the limited volume on top of the vehicle. For this reason, metal clamps were used to prevent the stretcher from folding. Furthermore, straps and an additional solid stretcher (seen in orange color) were added to secure the patient during transport.

A reliable locking mechanism for the stretcher is also needed in order to transport a victim safely. For this purpose, the platform was modified to accommodate both the wheel and the leg ends of the stretcher (see Fig. 4):

- Wheel-end. As seen in Figure 4(a), a metal bracket has been added to restrict the movement of the wheel in all directions but one, in order to allow roll-in and roll-out.
- Legs-end. A locking mechanism has been implemented in Rambler for the left and right legs of the stretcher, as seen in Figure 4(b). This mechanism consists of two different parts. The first one is a rectangular enclosure where the stretcher leg fits, which limits the movement of the legs but from the perpendicular direction of Rambler's surface. The second is a manual mechanism that allows locking and unlocking the vertical motion of the legs.

IV. Validation Exercise

A. Exercise development

The exercise was performed under realistic conditions in a one-shot basis. Rescue team members were not familiar with the robotic system prior to the exercise day. That same morning, they were briefed about the robotic stretcher and practiced shortly with the stretcher roll-in and locking mechanism. Stretcher insertion and fastening with the human volunteer were also tried at this point so as to confirm that a human, and not a dummy, would be finally carried during the evacuation phase of the exercise.

The mission lasted about 55 minutes from the explosion in the point-of-injury to the helicopter evacuation. Figure 5 shows a snapshot sequence of representative moments in the rescue mission:

a After a simulated explosion, Rambler was driven remotely to the point-of-injury, which was located within an unsafe hot zone with continuing attacks. One member of our research team (seen in the photograph) accompanied the robot and the rescue unit for safety reasons, but he did not have to intervene during the exercise.

b The rescue unit removed the stretcher from the robot, extracted the casualty (dummy) from the rubble, and secured the patient with straps.

c The rescuers inserted the stretcher with the victim back onto the vehicle. At this point, the rescuers had to repeat the previous step, as there was some confusion regarding the correct orientation of the patient (i.e., feet at the stretcher's wheel end) in order to fit onto the adapted robot.

d The rescuers communicated with the command post that the stretcher with the casualty had been successfully locked. Then, teleoperation was resumed to take the vehicle to the first response post in the safe area.

e The rescue team escorted the robot while further attacks continued in the background. At this point, the unit members showed some concern about the pace of the

Fig. 5. Sequence of images for the two phases of the exercise: casualty extraction (a-g) and evacuation (h-l).

vehicle, which they considered too slow for an attack situation.

- f The vehicle reached the first response post.
- g The stretcher with the casualty was removed from the robot for initial medical care. At this point, the extraction phase was successfully completed. A helicopter was requested for transporting the casualty to a medical treatment facility.
- h For the evacuation phase, the dummy was substituted by a human volunteer, who was secured onto the stretcher and inserted in the vehicle. For safety reasons, the operator (seen in the image) used the portable interface with sightline control of the vehicle.
- i After reaching the helicopter evacuation area, the stretcher was removed from the robot to wait for the helicopter approach. The patient is protected by the rescuers from dust and sand projected by the helicopter.
- j A rescuer descended from the helicopter (on the right side of the image) and the casualty was transferred to a litter basket.
- k The UGV returned to the command post area.
- l The casualty was evacuated in the helicopter.

B. Discussion and Lessons Learned

Overall, the results were satisfactory, with some issues to take into consideration. The major lessons learned from this validation exercise are the following:

- According to the unit personnel, the speed of the robot was too slow during the extraction procedure in the unsafe area under enemy fire. Even if the vehicle can reach up to 80km/h in straight line, we had decided to limit speed for safety reasons. Thus, follow-the-leader modes are desirable to adapt the pace, but in any case a compromise between speed and safety for the victim has to be established on rough terrain. Interestingly, for the evacuation phase, where the dummy had been substituted by a person, we asked the unit members about increasing the speed and the answer was negative.
- When inserting the stretcher back onto the vehicle at the Point-of-injury (see Fig. 5(c)) there was some confusion regarding the roll-in direction with respect to the vehicle orientation. This situation could have been avoided by adding clear informative signs on the robot's platform.
- Due to the dust and sand projected by the helicopter, the onboard router was damaged. It is critical to protect electronic devices and to consider redundancy of the most vital ones.

All in all, the robotic stretcher system worked successfully and its use was straightforward for the rescue personnel, who only required a short demonstration. This demonstration consisted of how the victim should be placed, the stretcher roll-in mechanism, and how to firmly secure the casualty to the stretcher. The short briefing was enough to safely evacuate the victim to the first response post and, later, to the helicopter evacuation area.

V. Conclusions

In this paper we have described a cooperative search and rescue exercise where an unmanned ground vehicle (UGV) was tested by a military rescue team for extraction and evacuation of a casualty from an unsafe man-made disaster area. This experimental validation was performed as part of a full-scale emergency response exercise conducted on June 2019 in Málaga (Spain).

The major goal was to adapt the Rambler robot to incorporate a stretcher roll-in and locking mechanism that was safe for human movement with an all-terrain UGV and which could be used in a simple and straightforward way by real responders. The mission consisted of two phases: first, extraction from the hot zone was performed with remote teleoperation using a dummy; second, casualty evacuation (CASEVAC) to an aeromedical evacuation point was done with sightline teleoperation moving an actual volunteer.

The exercise was performed on a one-shot basis under realistic conditions by military personnel with no previous experience with the robotic system. Feedback from the users indicates overall satisfaction with the robotic system. The major recommendations for improvement focused on the incorporation of a follow-me system so that the UGVs pace could be adapted to that of the rescue team members.

Acknowledgments

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References

[1] J. Delmerico, S. Mintchev, A. Giusti, B. Gromov, K. Melo, T. Horvat, C. Cadena, M. Hutter, A. Ijspeert, D. Floreano, L. M. Gambardella, R. Siegwart, and D. Scaramuzza, "The current state and future outlook of rescue robotics," *Journal of Field Robotics*, vol. 36, no. 7, pp. 1171–1191, 2019.

[2] B. Brüggemann, D. Wildermuth, and F. E. Schneider, "Search and retrieval of human casualties in outdoor environments with unmanned ground systems -system overview and lessons learned from ELROB 2014," *International Conference on Field and Service Robotics, FSR 2015. Springer Tracts in Advanced Robotics*, vol. 113, pp. 533–546, 2016.

[3] A. Williams, B. Sebastian, and P. Ben-Tzvi, "Review and analysis of search, extraction, evacuation, and medical field treatment robots," *Journal of Intelligent and Robotic Systems: Theory and Applications*, vol. 96, no. 3-4, pp. 401–418, 2019.

[4] A. C. Yoo, G. R. Gilbert, and T. J. Broderick, "Military robotic combat casualty extraction and care," *Surgical Robotics: Systems Applications and Visions*, pp. 13–32, 2011.

[5] Y. Iwano, K. Osuka, and H. Amano, "Development of rescue support stretcher system," in *IEEE International Workshop on Safety, Security, and Rescue Robotics*, 2010.

[6] ——, "Development of rescue support stretcher system with stair-climbing," in *IEEE International Symposium on Safety, Security, and Rescue Robotics, SSRR 2011*, 2011, pp. 245–250.

[7] R. Saputra and P. Kormushev, "ResQbot: a mobile rescue robot with immersive teleperception for casualty extraction," *Towards Autonomous Robotic Systems (TAROS 2018). Lecture Notes in Computer Science*, vol. 10965 LNAI, pp. 209–220, 2018.

[8] Google, "Aerial view of the UMA search and rescue experimental area," URL https://goo.gl/maps/EC2v2y1LtbRvBu4M7, 2020, accessed August 28, 2020.