

Robotics Applications in Natural Hazards

Minhao Wu *

Department of Civil and Environmental Engineering, University of California, Los Angeles, Los Angeles, United States

* Corresponding author: minhaowu10@g.ucla.edu

Abstract. Natural hazards not only have great contribution to fatality but also economic loss. Although government has proposed well developed policies to rapidly handle emergencies and systematically organized recovery actions, failures of emergency relief, such as ineffective rescue, can significantly increase the post-hazard death rate. With the advance of artificial intelligence, the use of robots for disaster management applications is a new trend in managing and accessing natural disasters. Disaster response robotics is capable of assisting and replacing rescue teams working in dangerous scenarios, which not only alleviates labor-intensity but also reduces the potential risks associated with rescue personnel. Research on construction automation has advanced, but extensive development is required to reach fully autonomous construction in disaster management and post-disaster recovery. Instead, human robotics collaboration is promising and able to effectively alleviate the knowledge deficit and confusion. In the article, different functions of disaster response robotics are introduced, and technical challenges and future improvements are described.

Keywords: Robotics, Natural hazards, Disaster recovery.

1. Introduction

Earthquakes, fires, floods, hurricanes, tsunamis, and other unpredictable crises frequently occur in societies, which result in significant deaths, injuries, and property damage, thus making their management imperative. According to the research, natural disasters globally kill on average 45,000 people per year [1]. Victims' total injuries due to natural hazards can be classified into two categories, direct injury (direct, unavoidable, negative impact of natural disasters on the human) and indirect injury (improper actions result in avoidable injury). For example, in the case of earthquakes, direct injury is an unavoidable injury caused by primary earthquakes and aftershocks, and the indirect injury occurs when the rescue team perform improper rescue actions, resulting in secondary collapse of buildings or doesn't response timely, causing injuries that could have been avoided after the earthquake events [2]. Additionally, inefficient institutions, poor infrastructure, and scarcity of resources make developing economies more vulnerable [3]. The people who have worked 48 to 72 hours straight in relief work have often risked personal injury and suffering in order to save lives [4]. Therefore, to avoid indirect injury and reduce the potential risks for rescue personnel to work in dangerous situations, robotics is used as a rapid and effective tool to assist human work and replace real human actions in extreme conditions.

In the aftermath of a disaster, the response must be swift enough to reach all possible survivors, yet slow enough to prevent additional collapses, damage, danger to rescuers, and contention over airspace. In order to save lives, robots can either interact directly with victims or structures or automate support activities [5]. This paper aims to review the current robotic technologies appropriate for disaster response and recovery and suggests strategies from a robotics perspective that would enhance disaster response and recovery. The article is organized as follows: an overview of the latest developments in robotic applications in natural hazards is presented in Section 2, and Section 3 summarizes the findings and discusses future research.

2. Robotics in Disaster Management

A disaster is a situation that puts human life at risk. The deployment of robotics in natural disaster management has been on the rise for the past few years. Rescue and recovery tasks performed by robots can be divided into three categories: 1. Surveying and Mapping the environment. 2. Searching and Rescue disaster victims 3. Reconstruction [6]. In this section, disaster response robots are introduced in different scenarios:

2.1. Surveying and Mapping

In order to support humanitarian efforts, georeferenced data associated with affected areas can be produced by early impact analysis after a disaster. Images from satellites are mainly used to analyze early impacts on medium and large-scale maps and high-resolution satellite images are utilized to analyze damage to infrastructure and facilities [7]. With centimeter-scale spatial resolution as well as the ability to deploy rapidly and repeatedly, UAV, as a relatively inexpensive tool, which can access otherwise inaccessible areas in a safe manner, are widely used for surveying. UAV surveying has been applied in multiple real disaster cases including:

1) Hurricanes: High resolution aerial images are acquired by UAV from different Hurricane Maria-affected key sites in Dominica in order to generate a digital surface model (DSM) and orthophotographs for quantitative analysis of hurricane impacts [8]. In order to evaluate the effect of Hurricane Harvey on upper Texas coastal areas, topographic data is collected from UAV for comparison between single-year or multi-year beach dune studies at a centimeter-level spatial resolution [9]. UAV-based preliminary assessment is conducted in order to evaluate mangrove damage caused by Cyclone Yolanda and monitoring post-hazard recovery [10].

2) Earthquakes: Road monitoring and secondary disaster investigation are conducted by routinely manipulating UAV after Wenchuan Earthquake in China [11]. Integration of terrestrial laser scanners and UAV photogrammetry data is used to build 3D modeling of damaged buildings in hazard affected communities in Greece and Italy [12, 13]. Earthquake-induced landslides are mapped based on UAV imagery in Greece [14].

3) Flooding: UAV are used for acquiring accurate and up-to-date spatial information on river environments, as well as monitoring fluvial processes in Poland [15]. In Transylvania, a UAV was used to delimit flood-prone areas in the north-east of the Apuseni Mountains [16]. To assist in monitoring during critical events such as heavy rains or flooding, UAVs are used to map rivers and estuaries [17].

Researchers are increasingly implementing UAVs in managing critical situations, and disaster management use UAVs for monitoring and surveillance. Photogrammetry technology of UAVs has proven to be very useful and efficient in decision making when a disaster occurred by discovering surface deformation. The important role of UAVs in the early warning is monitoring forecasts and gathering information before a disaster occurs, which significantly reduces potential risk and loss.

2.2. Rescue

Robotic disaster rescue systems are designed to prevent the spread of disaster damage in an emergency situation, including search and rescue operations as well as recovery activities [18]. For victims who cannot be reached easily, rescue robots can help locate, assess, stabilize, and extricate them. Various rescue robotics have been used in different cases, which can be classified into two categories:

1) Unmanned Ground Vehicles

Small unmanned ground vehicles (SUGVs) can be used to locate trapped victims in tight or dangerous spaces that humans and dogs cannot access [5]. Thermal image and computer vision algorithms are widely used in survivor detection. An infrared vision-based robotic survivor detection system has been proposed and validated in an inactive underground space in Poland. Collaborated with infrared thermography and RGB-D camera, this system consists of an unmanned ground vehicles

equipped with sensors and an image processing module that are based on adaptations of the algorithm You Only Look Once (YOLO) and the algorithm Histogram of Oriented Gradients (HOG), which can be used to verify the presence of humans [19]. A snake-like robot is developed to interact with humans and perform rescue tasks in narrow spaces. It consists of a five-fingered anthropomorphic robotic hand that is capable of grasping and manipulating a variety of objects [20]. Large unmanned ground vehicles (LUGVs) are intended to be mobile base stations, such as transporting injured victims and serving as a platform for small UGVs [21]. LUGVs should also be equipped with powerful manipulators to perform heavy duties, such as excavating and clearing debris [22]. When disasters strike, public communication infrastructure is particularly damaged, hindering search and rescue operations, and reestablishing functioning communication infrastructure is time consuming. Therefore, it is possible to use LUGVs to provide an adaptable and reliable emergency communication backbone, as well as to provide a wide range of sensing capabilities, which enables them to send data to field operators, increasing their situational awareness, while meeting the requirement of traversing rough terrain [23].

2) Unmanned Underwater Vehicles

Unmanned underwater robots can alleviate rescue delays and provide useful equipment for underwater research in areas affected by flooding or tsunamis [24]. The most common submarine rescue problems are: (i) being trapped in a confined space in the deep ocean (ii) losing communication between the submarine and base station [25]. Various types of UUVs have been applied in real situations. An octopus-like robot (OIR) is used for surveillance operations to investigate the underwater environment under control and capture some objects in the military [26]. After the 2011 Tohoku earthquake and tsunami, the Anchor Diver III robot was applied to perform search and rescue operations in Japan equipped with a high-resolution camera and a two-dimensional sonar [27]. A UUV equipped with a sonar, camera and powerful manipulator which can be remotely controlled by crews via tethers while searching for victims or conducting heavy duties was used after the Greater Eastern Earthquake in Japan. To alleviate the potential malfunction of a single UUV during the rescuing work, Multi-UUVs system is proposed by using an efficient Reward acting on Reinforcement Learning and Particle Swarm Optimization (R-RLPSO) and has been validated in 3D underwater environments [28]. There are also many researchers who investigate the communication between underwater operations and base stations [29]. PSK modulation technique was found to allow communication between two peers in deep water at 500 kbps over a distance of 60 meters. However, several challenges associated with underwater networking, such as power limitations, limited bandwidth, fading, high propagation delay, and bit error rates and safety issues [30]. To remove these limitations, the integration of unmanned aerial-aquatic vehicle (UAUVs) and UUV is capable of searching underwater targets from the air and sending the information to AUVs after they dive into water, which will improve work efficiency and ensure vehicle safety [31].

During disaster recovery operations, rescue robots play a crucial role. A rescue robot is a powerful tool for searching for survivors during and after a disaster, providing first aid treatment to survivors, and informing the rescue team about environmental conditions and possible survivors, which greatly enhances the ability to carry out rescue operations.

2.3. Reconstruction

Reconstruction after a natural hazard is crucial to reestablishing socioeconomic growth. It has been found, however, that the reconstruction process is often slow and lacks efficiency due to the safety issue and dangerous situation in post-disaster recovery, as well as cleaning up debris requires a long time [32]. Due to the advancement in construction automation, the industry has invested in the automation of conventional earthmoving equipment and the adoption of prefabrication in order to reduce the amount of onsite labor [33]. As a result of the use of robotics in the construction industry, productivity is expected to increase, labor shortages will be eliminated, and safety risks will be reduced, particularly during the recovery process after a disaster [34]. To reduce potential secondary injury during post-disaster reconstruction, telemanipulation robots are widely used. Various

teleoperated excavators was developed by using the master-slave system to operate in high-risk areas. A master-slave system is a system where the master works remotely and directly control slave systems by sending commands. With the advancement of robotics, in order to alleviate potential human fatigues and risks, a humanoid robot or a subordinate system is capable of replacing real human acting on behalf of human operators to command the excavators or slaves, by receiving commands from the operator or master [35]. Teleoperated construction robots have been applied in many real post-disaster recoveries. A construction machinery with a dual-arm, double front design has been introduced in Japan, which features two six-degrees-of-freedom manipulators with a grasping mechanism which consists of five single-rod hydraulic cylinders and a hydraulic motor [36]. In order to improve the grasping motion of soft objects, a force feedback joystick operated by a grapple-attached excavator was developed to improve the grasping motion through force feedback application [37]. Teleoperated electrohydraulic actuators equipped with radio-controlled transmitters and receivers have been employed by construction vehicles in Malaysia. A 24 VDC electrohydraulic valve coupled with a tie-rod cylinder was used to develop the telerobotic platform [38]. In order to pump and place concrete into the formwork, vehicle-mounted manipulators with concrete pumps are used, such as the robotic system developed by Tunconstruct. Due to reactive pump control features and semi-autonomous boom control, these manipulators are easy to handle, which minimizes the potential for mistakes [39].

In addition to providing a highly controlled fabrication environment, robotic arm based modular construction eliminates transportation costs associated with workers and equipment to the job site and increases overall productivity as the site is not affected by post-disaster conditions. The equipment can be installed permanently for mass production, thereby increasing efficiency over the reconstruction process on site [40].

3. Conclusion

As science and technology evolve, human minds and behaviors change much faster than social adaptation. It is necessary for all stakeholders to work together to solve social, industrial, and technical issues in order to implement disaster robotics. It has been demonstrated that current robotic systems are capable of being applied to disaster relief operations. However, it remains challenging to overcome engineering challenges. Due to the high complexity of the post-disaster environment, robots are unreliable to be used extensively because of their inflexibility and adaptiveness, especially for rescue. For example, buildings can be damaged and collapsed by earthquake ground shaking as well as can sink into the ground if soil liquefaction occurs. Large earthquakes sometimes result in flooding and tsunamis, which produces landslide dams. Victims are also possible to be buried under ruins surrounded by flooded areas. It is not intelligent enough for current robots with sole function or without adaptations to various environments to execute tasks with full automation in these situations. Human intervention is still required. Although the success of teleoperated heavy-duty construction machines in disaster recovery operations, wireless communications remain a challenge. Existing robots have difficulty establishing reliable communication to the base station over long distances, which makes them inefficient at fulfilling their tasks. Despite studies that have been conducted on 3D mapping of job sites, there remain questions as to whether such a method will address cognitive overload caused by excessive information provided to operators and the latency issue resulting from teleoperating excavators. Furthermore, since robots rely on batteries, their deployment is also severely restricted by the type and capacity of their batteries. Consequently, future studies should confirm whether the 3D mapping is feasible for teleoperating excavators on sites. The hybrid system is promising, such as hybrid of UAV and UGV systems or collaboration among multiple UGV systems.

Combining human supervision with robot intelligence is crucial for disaster robot usability with current robotic technologies. Instead of achieving full automation, human-robot interaction (HRI) allows off-site operators to control robots and gain situational awareness through a video stream or other sensory data, which is essential for heterogeneous solution to cover disaster areas. For example, electroencephalogram (EEG) has been successfully proved to be useful as input data for brain-

machine interface. The brain-machine interface can be remotely controlled by different features of worker's brainwaves obtained by a wearable sensor. Robots can then be modified to meet workers' needs at the job site, improving safety and productivity. In order to conduct more in-depth studies in the future, it is necessary to consider the risks, the difficulties, and the different levels of time pressure of the task. To succeed in critical zones, rescue robots must be more advanced, intelligent, and have robust and reliable hardware in order to deal with any obstacle that may arise.

References

- [1] Alexander D. (2018). Natural disasters [M]. Routledge.
- [2] Johnston, D., Standring, S., Ronan, K., Lindell, M., Wilson, T., Cousins, J., ... & Bissell, R. (2014). The 2010/2011 Canterbury earthquakes: context and cause of injury. *Natural Hazards*, 73 (2), 627 - 637.
- [3] Khan, M. T. I., Anwar, S., & Batool, Z. (2022). The role of infrastructure, socio-economic development, and food security to mitigate the loss of natural disasters. *Environmental Science and Pollution Research*, 1 - 26.
- [4] Srivastava, K. (2010). Disaster: Challenges and perspectives. *Industrial psychiatry journal*, 19 (1), 1.
- [5] Murphy, R. R., Tadokoro, S., & Kleiner, A. (2016). Disaster robotics. In *Springer handbook of robotics* (pp. 1577-1604). Springer, Cham.
- [6] Park, S., Oh, Y., & Hong, D. (2017). Disaster response and recovery from the perspective of robotics. *International Journal of Precision Engineering and Manufacturing*, 18 (10), 1475 - 1482.
- [7] Xu, Z., Yang, J., Peng, C., Wu, Y., Jiang, X., Li, R., ... & Tian, B. (2014). Development of an UAS for post-earthquake disaster surveying and its application in Ms7. 0 Lushan Earthquake, Sichuan, China. *Computers & Geosciences*, 68, 22 - 30.
- [8] Schaefer, M., Teeuw, R., Day, S., Zekkos, D., Weber, P., Meredith, T., & Van Westen, C. J. (2020). Low-cost UAV surveys of hurricane damage in Dominica: automated processing with co-registration of pre-hurricane imagery for change analysis. *Natural hazards*, 101 (3), 755 - 784.
- [9] Rojas, S. S., Khan, S. D., & Shahtakhtinskiy, A. (2022). Impact of Hurricane Harvey on the Upper Texas Coast: Using Airborne Lidar Data Sets with UAV-Derived Topographic Data to Monitor Change and Track Recovery. *Remote Sensing*, 14 (21), 5357.
- [10] Primavera, J. H., Dela Cruz, M., Montilijao, C., Consunji, H., Dela Paz, M., Rollon, R. N., ... & Blanco, A. (2016). Preliminary assessment of post-Haiyan mangrove damage and short-term recovery in Eastern Samar, central Philippines. *Marine pollution bulletin*, 109 (2), 744 - 750.
- [11] Xu, Z., Yang, J., Peng, C., Wu, Y., Jiang, X., Li, R., ... & Tian, B. (2014). Development of an UAS for post-earthquake disaster surveying and its application in Ms7. 0 Lushan Earthquake, Sichuan, China. *Computers & Geosciences*, 68, 22 - 30.
- [12] Chatzistamatis, S., Kalaitzis, P., Chaidas, K., Chatzitheodorou, C., Papadopoulou, E. E., Tataris, G., & Soulakellis, N. (2018). Fusion of TLS and UAV photogrammetry data for post-earthquake 3D modeling of a cultural heritage Church. *Proceedings of the Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, 143 - 150.
- [13] Dominici, D., Alicandro, M., & Massimi, V. (2017). UAV photogrammetry in the post-earthquake scenario: case studies in L'Aquila. *Geomatics, Natural Hazards and Risk*, 8 (1), 87 - 103.
- [14] Valkaniotis, S., Papathanassiou, G., & Ganas, A. (2018). Mapping an earthquake-induced landslide based on UAV imagery; case study of the 2015 Okeanos landslide, Lefkada, Greece. *Engineering geology*, 245, 141 - 152.
- [15] Popescu, D., Ichim, L., & Caramihale, T. (2015, October). Flood areas detection based on UAV surveillance system. In *2015 19th International conference on system theory, control and computing (ICSTCC)* (pp. 753-758). IEEE.
- [16] Șerban, G., Rus, I., Vele, D., Brețcan, P., Alexe, M., & Petrea, D. (2016). Flood-prone area delimitation using UAV technology, in the areas hard-to-reach for classic aircrafts: case study in the north-east of Apuseni Mountains, Transylvania. *Natural Hazards*, 82 (3), 1817 - 1832.

- [17] Mancini, A., Frontoni, E., Zingaretti, P., & Longhi, S. (2015, June). High-resolution mapping of river and estuary areas by using unmanned aerial and surface platforms. In 2015 International Conference on Unmanned Aircraft Systems (ICUAS) (pp. 534-542). IEEE.
- [18] Tadokoro, S. (2020). Disaster Response Robot. In: Baillieul, J., Samad, T. (eds) Encyclopedia of Systems and Control. Springer, London. https://doi.org/10.1007/978-1-4471-5102-9_181-2.
- [19] Szrek, J., Zimroz, R., Wodecki, J., Michalak, A., Góralczyk, M., & Worsa-Kozak, M. (2020). Application of the infrared thermography and unmanned ground vehicle for rescue action support in underground mine—The amicos project. *Remote Sensing*, 13 (1), 69.
- [20] Han, S., Chon, S., Kim, J., Seo, J., Shin, D. G., Park, S., ... & Cho, J. (2022). Snake Robot Gripper Module for Search and Rescue in Narrow Spaces. *IEEE Robotics and Automation Letters*, 7 (2), 1667 - 1673.
- [21] Berns, K., Nezhadfar, A., Tosa, M., Balta, H., & De Cubber, G. (2017). Unmanned ground robots for rescue tasks. In *Search and Rescue Robotics-From Theory to Practice*. IntechOpen.
- [22] Yoshinada, H., Kurashiki, K., Kondo, D., Nagatani, K., Kiribayashi, S., Fuchida, M., ... & Tadokoro, S. (2019). Dual-arm construction robot with remote-control function. In *Disaster Robotics* (pp. 195-264). Springer, Cham.
- [23] De Cubber, G., Serrano, D., Berns, K., Chintamani, K., Sabino, R., Ourevitch, S., ... & Baudoin, Y. (2013, October). Search and rescue robots developed by the european icarus project. In 7th Int. Workshop on Robotics for Risky Environments. Citeseer.
- [24] MOHAMMAD, P. Underwater Research and Rescue Robot.
- [25] Tijjani, A. S., Chemori, A., & Creuze, V. (2022). A survey on tracking control of unmanned underwater vehicles: Experiments-based approach. *Annual Reviews in Control*.
- [26] Zhu X, Xu H, Zhao Z. (2021). An Environmental Intrusion Detection Technology Based on WiFi. *Wireless Personal Communications*, 119(2): 1425-1436.
- [27] Huang, Y. W., Sasaki, Y., Harakawa, Y., Fukushima, E. F., & Hirose, S. (2011, September). Operation of underwater rescue robot anchor diver iii during the 2011 tohoku earthquake and tsunami. In *OCEANS'11 MTS/IEEE KONA* (pp. 1-6). IEEE.
- [28] Wu, J., Song, C., Ma, J., Wu, J., & Han, G. (2021). Reinforcement learning and particle swarm optimization supporting real-time rescue assignments for multiple autonomous underwater vehicles. *IEEE Transactions on Intelligent Transportation Systems*.
- [29] Heidemann, J., Ye, W., Wills, J., Syed, A., & Li, Y. (2006, April). Research challenges and applications for underwater sensor networking. In *IEEE Wireless Communications and Networking Conference, 2006. WCNC 2006*. (Vol. 1, pp. 228-235). IEEE.
- [30] Akyildiz, I. F., Pompili, D., & Melodia, T. (2005). Underwater acoustic sensor networks: research challenges. *Ad hoc networks*, 3(3), 257-279.
- [31] Wu, Y. (2019). Coordinated path planning for an unmanned aerial-aquatic vehicle (UAAV) and an autonomous underwater vehicle (AUV) in an underwater target strike mission. *Ocean Engineering*, 182, 162 - 173.
- [32] McCaughey, J. W., Daly, P., Munder, I., Mahdi, S., & Patt, A. (2018). Socio-economic consequences of post-disaster reconstruction in hazard-exposed areas. *Nature Sustainability*, 1 (1), 38 - 43.
- [33] Melenbrink, N., Werfel, J., & Menges, A. (2020). On-site autonomous construction robots: Towards unsupervised building. *Automation in construction*, 119, 103312.
- [34] Zhang, H., Dolan, C., Jing, S. M., Uyimleshi, J., & Dodd, P. (2019). Bounce forward: economic recovery in post-disaster Fukushima. *Sustainability*, 11 (23), 6736.
- [35] Ostoj-Starzewski, M., & Skibniewski, M. (1989). A master-slave manipulator for excavation and construction tasks. *Robotics and Autonomous Systems*, 4 (4), 333 - 337.
- [36] Tang, X., & Yamada, H. (2011). Tele-operation construction robot control system with virtual reality technology. *Procedia Engineering*, 15, 1071 - 1076.
- [37] Ito, M., Funahara, Y., Saiki, S., Yamazaki, Y., & Kurita, Y. (2019). Development of a cross-platform cockpit for simulated and tele-operated excavators. *Journal of Robotics and Mechatronics*, 31 (2), 231 - 239.

- [38] Yusof, A. A., Saadun, M. N. A., Sulaiman, H., & Sabaruddin, S. A. (2015, October). Modern practical application and research on teleoperated excavators' control, feedback and perception issues in post disaster recovery operation. In 2015 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS) (pp. 179-185). IEEE.
- [39] Nabulsi, S., Rodriguez, A., & Rio, O. (2010, June). Robotic machine for high-quality shotcreting process. In ISR 2010 (41st International Symposium on Robotics) and ROBOTIK 2010 (6th German Conference on Robotics) (pp. 1-8). VDE.
- [40] Cai, S., Ma, Z., Skibniewski, M. J., & Bao, S. (2019). Construction automation and robotics for high-rise buildings over the past decades: A comprehensive review. *Advanced Engineering Informatics*, 42, 100989.