

Application of Robotics in Disaster Recovery

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***Abstract*—Recovery of people in the wake of disasters has been and continues to be a signature challenge of disaster response. Infrastructure damage and unforgiving conditions caused by natural and artificial disasters alike create tricky scenarios where traditional extraction or response methods are not viable options. Robotics, however, may fill that gap by serving as a more efficient, cost-effective, scalable, and safe method for disaster response personnel to apply. This research paper aims to cover the various applications of robotics in disaster recovery. Specifically, the location and extraction of victims of natural disasters and security crises, and the containment of disaster zones.**

DISASTER RESPONSE TECHNOLOGIES AND ROBOTICS

A. Types of Search and Rescue Robots

1) Overview

Search and rescue robots are designed for dangerous, inaccessible, or contaminated areas. They are invaluable tools that give emergency

personnel the leverage needed to respond quickly in affected areas that would otherwise be too dangerous, uncertain, and risky. Robotics has presented itself as a solution that fills gaps in disaster response efficiency; their continuous function without fatigue, lack of fear, expendability, and real-time information relaying serves to be the primary advantage of using robots in disaster recovery and search and rescue [9]. This section will go over the different types of search and rescue robots, and the applications specific to each.

1) Ground Robots

Ground robots are capable of traversing ground and terrain, and often come equipped with sensors and cameras that allow them to navigate their environment and detect objects of interest [2]. In search and rescue and disaster response, ground robots are often deployed to areas that are too dangerous, difficult, or time-consuming to navigate on foot to search for survivors or get real-time disaster updates [9]. They can access areas that may prove too risky for first responders, and can also provide

supplies to inaccessible areas [9]. Ground robots are also a safe tool to use for assessing how dangerous an area is, measuring contamination levels, and sealing leaks; these critical tasks are often not feasible or safe for emergency personnel to complete after nuclear disasters or toxic spills [9].

2) Aerial Robots

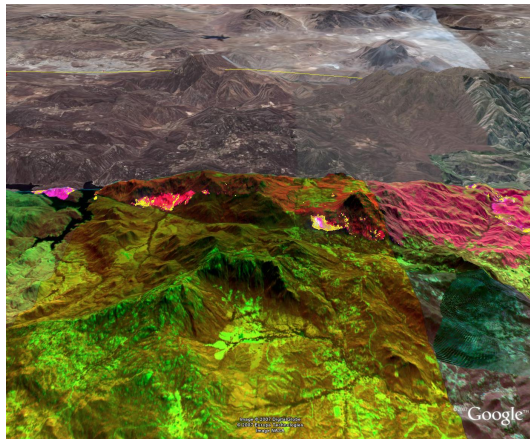


Fig. 1: Infrared Drone Imaging of 2007 San Bernardino Mountains Wildfire
Source: [8]



Fig. 2: Aerial Infrared Imaging of 2025 Wildfire in Alabama
Source: [7]

Unmanned aerial vehicles (UAVs) can survey and view wide areas quickly, capture thermal and visual images, and locate many things using heat signatures or visual aspects [2, 4]. Drones like DJI and Lockheed Martin Indigo are widely used, which helps view areas a lot faster than a human on foot. Arguably, the most advantageous utility of aerial robots in search and rescue is real-time communication and relaying of information. Aerial drones take birds-eye views that provide critical information and situational awareness about the terrain and disaster containment [3]. Emergency responders can combine digital models with real-time

visuals from the sky to better understand and predict how a disaster such as a wildfire or flash flood may be developing over time and change response plans accordingly, as shown in Figure 1 and Figure 2 [3, 7, 8, 9].

3) Aquatic Robots

In cases of floods, tsunamis, or collapsed structures near water, underwater robots such as ROVs (Remotely Operated Vehicles) search submerged areas for survivors or survey damages to infrastructure [5].

B. Advantages of Robotics in Disaster Recovery

- Operate in environments too dangerous for humans
- Minimize risk to rescue personnel
- Provide real-time data and mapping
- Work continuously without fatigue
- Perform precise, repetitive tasks efficiently

C. Limitations and Challenges

1) Overview

Robots extend the life-saving and disaster recovering capabilities of first responders, but are certainly not without their own set of unique limitations and challenges. Although robots make up for their limitations in their utility and other areas, human first responders have the mobility, human-human interaction capabilities, sensory processing capabilities, speed, and experience that robots often lack.

2) High Cost and Maintenance Demands

Robots in general are very expensive and difficult to maintain. They often require specialized teams for operation, maintenance, and repair. The mountain of technical expertise, resources, and finances that must be poured into organizations (which often have limited budgets) often bottlenecks the application of robots in tasks such as search and rescue [11]. In developing countries, without certain technological resources, qualified personnel, and technical training, robots become options too expensive, unscalable, or logistically impossible to implement [11].

3) *Battery Life*

Despite being able to work for hours on end without fatigue, robots currently lack the durability and battery life needed to respond to disasters for long periods of time. Unforgiving, unstable, and unpredictable terrain can “beat up” a robot’s intricate systems over time and require checks or repair [11]. In addition, remote areas with sparse access to power can limit a robot’s ability to recharge its batteries or for a maintenance/repair team to make repairs [11].

TYPES OF DISASTERS

A. *Natural Disasters*

1) *Hurricanes*

A hurricane is a gigantic tropical storm that forms over warm ocean waters [1]. The rising air mass from hot tropical water creates a low-pressure zone that draws in air from surrounding areas, and strong winds rush in to fill the space left behind [15]. When atmospheric conditions are right, these winds can develop into a tropical disturbance [15]. Earth’s rotation deflects the winds, causing them to spin around the low-pressure center, creating an “eye” at the center of the storm [15]. Hurricanes have powerful winds that blow things away like buildings and cars, heavy rain that causes flooding, and storm surges that flood coastal areas [1]. Meteorologists classify them based on their wind speed, with Category 5 being the most powerful [1].

2) *Tornadoes*

Tornadoes form when warm and cold air collide during thunderstorms. This collision can force the wind to start spinning in a circle [1]. One of the most common places for tornadoes to occur is a place called tornado alley in the middle section of the United States, where cold, dry air from the Mexican plateau and moist tropical air from Texas and the Gulf of Mexico collide [15]. Like hurricanes but on a smaller scale, these circling masses of wind can be so strong that they can pick up houses, cars, and trees and toss them around like toys [1].

3) *Volcanoes*

Volcanoes form from hot molten rock, ash, and gases from deep within the Earth. They can burst out through an opening, often creating an eruption [1]. They typically occur where two plate tectonic boundaries meet, such as the Ring of Fire in the Pacific Ocean [13]. They have around 75% of all the volcanoes on Earth [13]. But they can also happen at subduction zones, hot spots, and mid-oceanic ridges [1]. A volcano explodes due to a spike in the Earth’s internal activity, leading to massive amounts of lava and ash being released [1].

4) *Earthquakes*

An earthquake happens when there’s a sudden release of energy in the Earth’s crust [1]. This creates seismic waves that cause the ground to shake [1]. This release of energy happens because of the movement of tectonic plates beneath the Earth’s surface [1]. Many earthquakes also form around the Ring of Fire due to the seismic activity there, amounting to around 90% [13]. Earthquakes can range in size and strength, from small ones that are hard to notice to big ones that can damage buildings and landscapes [1]. They can also lead to aftershocks, which are smaller tremors that follow the main earthquake [1]. In the face of the destruction brought about by earthquakes, robots have proved themselves effective in responding to them and locating survivors trapped under rubble. For example, after the twin 7.8-magnitude earthquakes that hit both Syria and Turkey in 2023, drone teams flew drones equipped with thermal cameras that enabled search and rescue teams to locate victims even in low-visibility nighttime conditions and provide 24/7 response [11]. Drones have also been used to determine the structural integrity of buildings after earthquakes such as the one that hit Mexico City in 2017; the drones applied algorithms and took images to create a 3-D surface model of the affected building, which was then simulated and assessed for potential damages [11].

5) *Tsunamis*



Fig 3: Aftermath of 2004 Boxing Day Tsunami in Indonesia

Source: [12]

Tsunamis happen when something big, like an undersea earthquake, disturbs the ocean floor [1]. This disturbance creates a massive amount of energy, which sends powerful waves spreading across the ocean [1]. Although they are barely noticeable in the ocean, as these waves approach shallower coastal areas, they can grow in height and speed, causing massive flooding when they reach the shore [1, 14]. This wave can reach several miles inland, causing massive amounts of damage [14]. However, robots can lessen the disastrous impact of tsunamis after the wave has passed, rather than just in the heat of the moment. For example, during the 2004 Sri Lankan Boxing Day Tsunami event, much debris from infrastructure was left in the tsunami's wake, but with no proportional breakdown or relative scale of the types of debris and waste created [10]. Robotics can fill this critical gap of information blindness in emergency disaster response by sharing real-time updates and analyses of disaster outcomes, such as finding out relatively how much waste was created by the Sri Lankan Boxing Day Tsunami [10]. Such info would have allowed recovery efforts to plan in advance how they would tackle waste management rather than waste time and risk lives surveying the area on foot.

6) Droughts

A drought is a prolonged period of abnormally low rainfall in a particular region [1]. This can cause water shortages and impact the environment and agriculture [1]. This causes dry soil, less crop growth, and water restrictions for communities.

7) Landslides

A landslide is a sudden movement of dirt, rocks, or even entire chunks of land that suddenly moves downhill [1]. It can happen because of heavy rain, earthquakes, or other factors that make the ground unstable [1]. They often cause damage to homes, roads, and the natural landscape in the affected area [1].

8) Fires

A forest fire, also known as a wildfire, is when a forest suddenly catches fire and spreads quickly to the surrounding area due to the dry timber of a drought or a hot summer and gusty winds [1]. It's a fast-spreading, uncontrolled fire that occurs in forests, grasslands, or wild areas [1]. Fires can start from lightning, human activities, or even volcanic eruptions [1]. Robots can be specialized and made to be ideal tools for safely fighting fires. With reinforced heat-resistant alloys that maintain structural integrity even at high temperatures, robots can remotely and durably tackle wildfires in burning conditions [11]. In addition, aerial drones can quite paradoxically fight fire with fire by dropping small incendiary pouches ahead of the main fire, effectively starving the main fire of fuel; with aerial drones, this process is scalable and efficient [11].

9) Flooding

Water overflowing onto dry land is called flooding [1]. Flooding can occur because of heavy rain, melting snow, or rising rivers, lakes, or oceans. Floods can be slow and gradual, or they can come on quickly, like during a hurricane [1]. They can damage homes, roads, and farmland, and can be very dangerous [1]. Robots are well equipped for disaster response in the murky conditions that floods create. Using sonar, cameras, and diving capabilities, robots can search for victims trapped below the water level, or operate in submerged areas that first responders can't [11].

B. Artificial Disasters/Incidents

1) *Nuclear disasters*

Nuclear disasters—such as the Chernobyl and Fukushima Daiichi plant core meltdowns in 1986 and 2011, respectively—result in the expulsion of radioactive material that puts nearby civilians at heavily increased risk of Acute Radiation Sickness (ARS), cancer, and birth defects in pregnant women [17]. The aftermath of such incidents leave surrounding areas uninhabitable and dangerous to live in. These incidents can occur due to human error, like in Chernobyl, or even due to other natural disasters, like the Fukushima Daiichi core meltdown caused by the 2011 tsunami that slammed the coast of Japan and destroyed critical reactor coolers in the plant [17]. In the aftermath of Chernobyl, 28 emergency personnel died from radiation exposure while attempting to contain the meltdown. With vastly improved technology, robots can be utilized to respond to such incidents to remove the risk that emergency personnel would otherwise face. The aforementioned ground robots can navigate these plants remotely without fear of contamination, radiation exposure, or total infrastructure collapse while in the plant [11]. These robots can make measurements, assess the situation safely, and make critical seals/welds to stabilize damaged infrastructure and prevent further damage [11].

C. *Challenges that Disasters Produce*

1) *Decimation of Public Infrastructure and Waste Creation*

Disasters of all types bring about overwhelming amounts of often irreparable destruction and damage to urban and rural environments alike. The destruction of all this infrastructure creates debris, rubble, and waste that raises environmental and economical issues [10]. Such ruin is capable of rendering an area permanently inhabitable after certain disasters [3]. Perhaps most detrimentally, disasters sever essential public infrastructure that connect first responders to refugees and disaster victims, drastically slowing down response efforts. Cities become physically impossible to navigate after

certain disasters as airports, runways, heli-pads, roads, and highways are damaged [3].

2) *Lack of Resources to Rescue Victims*

The incredible and unpredictable amount of debris and rubble produced also makes it difficult for responding emergency personnel to locate disaster victims trapped beneath it. Even if victims are located, emergency personnel may not have access to the tools and heavy machinery needed to extract them [3]. Public infrastructure destruction can also make it impossible to fly in planes, helicopters, or drive in trucks to supply impacted areas. Disasters can also take out power supply systems and water pipelines that leave areas unsustainable for disaster responders to station themselves in [3].

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