The Current State of Search and Rescue Robot Concepts, its Complications, and its Potential

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Abstract

Search and Rescue robotics is becoming a fast-growing field as more ideas and designs are being developed and published. Designs range from robots with snake-like chassis to help navigate terrain to tank-drive chassis with a rocker arm to climb difficult obstacles. These designs come with benefits and limitations, and it is important to analyze them in order to determine what is the best solution. Despite their potential, Search and Rescue robots come with plenty of complications. An ineffective robot could end up endangering the lives of people it is trying to save, and there is no guarantee that the robot will not malfunction or receive damage along the way. In summary, Search and Rescue robots have the potential to save lives more effectively than human rescuers and prevent human rescuers from risking their own lives; however, these robots can also be susceptible to many problems, and a viable design solution is important in order to make them effective.

Introduction

Search and Rescue is a key part of emergency response operations. It involves locating and assisting endangered individuals from a variety of possible emergencies including natural disasters, hostage situations, and more [1]. Search and Rescue teams typically contain specialized and trained personnel who work on extraction and communication. These operations are very important as they are the first response to big emergencies and are one of the biggest factors in reducing the death count of events such as natural disasters. Search and Rescue operations typically take place in hazardous conditions such as in the ocean, in wilderness, or in disaster zones [1]. These environments come with lots of dangers, including large fallen obstacles, difficult navigation due to rubble and destroyed roads, strong winds or large waves, limited visibility, dangerous fumes, and more. Because of this, rescuers on these teams often put their lives in danger in order to locate individuals. During the rescue period after the 9/11 attacks, over 91,000 workers and volunteers were exposed to hazardous conditions. Out of these, 343 firefighters and paramedics along with 23 NYPD officers were killed during rescue operations [2]. Many others died years after the attacks from health problems caused by injuries and exposure [3]. These deaths, along with the many lives that had to be risked saving others, can be prevented through the use of Search and Rescue robots. These robots would be able to replace Search and Rescue extraction workers by navigating the terrain and searching for individuals. They have the potential to be more effective in searching for people and reach survivors faster than human rescuers. They can also navigate terrain better through the use of scanners, sensors, camera vision, and a chassis that can adapt to terrain. These benefits, in addition to the ability to mass produce these robots make them a great alternative to human rescuers [4]. There are currently many different types of Search and Rescue robot prototypes that serve different purposes. These robots range from drones which are used to scout the area to ground vehicles which can find survivors. This review will be focusing on land-based robots in order to have a more direct and effective comparison. Additionally, we will be assessing these robots based on their ability to navigate terrain and find survivors, as most current Search and Rescue robot designs do not include systems for communication with survivors and survivor extraction. Search and Rescue robots are currently in an early stage, but four main prototype designs have begun to emerge: tanks, rocker arm tanks, wheeled robots, and snake robots. This research paper will review the different designs and prototypes for rescue robots and determine which will be the most effective by analyzing them in multiple categories.

Search and Rescue robot subsystems

For a Search and Rescue robot to be effective, there are certain subsystems that are required. These include some kind of drivetrain for mobility and navigating terrain, and a variety of sensors and cameras in order to detect survivors and terrain as well as sending information back to the operators. The drivetrains can come in many forms, which will be discussed later. These drivetrains are specialized for the types of terrain they will be navigating through. As for sensors, a variety are needed in order to effectively navigate and locate survivors. Standard cameras are useful for the operators who are driving the robot in order for vision. These cameras must be mounted in a position where they give the maximum visibility. In addition to these cameras, sensors which can help detect obstacles, such as ultrasonic sensors, and sensors which can detect survivors, such as infrared sensors, are also a must [5].

Search and Rescue robot requirements

There are also certain requirements that must be met for a Search and Rescue robot. These robots cannot be too large, as this will make them difficult to transport quickly to necessary locations and will also make deploying them much harder. A large robot also creates drawbacks with costs and adaptability. Durability is another key factor with robot designs. Because these robots are going to be deployed in unpredictable situations and environments, they must be able to withstand many conditions including hot and cold temperatures, rain or wet conditions, and unique terrain conditions. Because of these numerous factors, Search and Rescue robots need to be durable enough to survive falls, completely waterproof, and must be manufactured so that the parts are well-built and are able to cover the electronics. One final requirement for Search and Rescue robots is ease of operation. A well-built robot will not be effective if the operators have a hard time controlling it, which means that an easy to use robot is essential. In order to make a robot easy to operate, it must not have too many subsystems or moving parts which the operators have to control, and certain processes should be automated. Communication systems also play a role in this. These robots should be able to send back information to operators effectively, as this information is what allows them to operate the robot. Having a strong wireless connection is essential for this [6].

Tank Robots

Tank drive search and rescue robot designs were some of the first designs ever created, and they continue to be used because of the unique benefits they provide. Tank designs consist of two to three wheels connected together by tread. The tread allows the tank drive to easily move over rough terrain and small obstacles. Larger treads are often used with these robots in order to provide more mobility over rough terrain.

Tank robots are effective search and rescue designs due to their simplicity, durability, and size flexibility. Tank drive designs are fairly simple because there is only one main feature in the drivetrain. Additionally, tank drive designs have a lot of pre-existing research behind them as they have been used for many other purposes. These two elements make tank drives simpler and easier to build than many other designs. Tank drive designs are also simple when it comes to operation, as the tank is the only moving element. A tank drive only needs one operator, and the controls for a tank are very simple. This means that a tank design will take minimal operator training time. Tank drives designs are also very flexible, allowing for a variety of shapes and sizes to be effective depending on the task. For search and rescue robots, smaller tank drives provide greater maneuverability through tight spaces and are cheaper while bigger tank drives allow the robot to climb over bigger and more unconventional obstacles, such as stairs. The lack of complexity in tank robots also allows for a more durable design. Tank designs have minimal weak points as the design does not consist of any joints or other areas susceptible to damage. This allows tank robots to survive big falls and big impacts with terrain better than most other designs. These advantages allow for tank robots to be a viable search and rescue robot design.

However, tank robots also have some important disadvantages. One of these disadvantages is its ability to climb large obstacles effectively. Small tank robots are unable to get enough grip to climb such obstacles, and large tank robots have to trade off maneuverability through small areas in order to climb bigger obstacles. Tank robots also struggle with getting out of ditches or other places where they might get stuck. This is because tank robots can only rely on the grip present on their tread to climb out of steep areas, and if it is in a position where it can't move, it has no moving parts which it can use to wiggle out.

Tank robot designs have been designed and used in competitions such as the Robocup Rescue League, where different Search and Rescue robots compete in multiple objectives simulating a real Search and Rescue scenario. Two examples of tank drive robots in the competition are Hector Darmstadt's 2019 robot and ATR team's 2019 robot [7, 8]. Hector Darmstadt's robot is a great example of an extremely compact tank robot. The robot's incredibly small dimensions allow it to maneuver very well and fit through gaps easily.

Figure 1: Hector Darmstadt 2019 robot [7]

The lack of complexity allows for a stable design which is less susceptible to damage than most other robots in the competition. These advantages allowed this robot to get third place in 2019, proving that a simple design can be very effective (Table 1). ATR team's robot is bigger, but it comes with its own advantages.

Figure 2: ATR Team 2019 robot

Firstly, it has a unique feature attached to the tank, which is the two tires in the back. These tires give the robot additional mobility by allowing it to climb over larger obstacles. For example, the robot is able to climb over steep surfaces such as stairs easier by using the back tires as support as the tank portion crawls up the wall [8]. This solves one of the biggest weaknesses of the tank robot, its ability to climb big obstacles. It also does not take away from the durability as the tires are securely integrated with the rest of the robot and do not contain an extra joint.

Outside of the Robocup Rescue League, Search and Rescue robots with tank designs are already being used. The Howe & Howe Thermite S1 is an example of a tank robot that can be used in Search and Rescue scenarios [9]. Although this robot was designed for firefighting purposes, it still contains features that enable it to cover rough terrain and search for survivors, which is needed for Search and Rescue scenarios. This robot is different compared to the robots in the Rescue League because of its enormous size. This allows it to climb over bigger obstacles including steep areas and stairs, as its large tread allows it to grip obstacles very well. Additionally, this robot is built with far stronger materials than the Rescue League robots, making it very durable and able to withstand many weather conditions [9].

Figure 3: Howe & Howe Thermite S1 [9]

The QinetiQ Dragon Runner 10 is another Search and Rescue robot which appears at the opposite end of the spectrum when it comes to size. It is built to be incredibly compact and light, weighing just around 10 pounds. Its size gives it the advantage of being extremely portable, as it is designed to be carried on the backs of rescue workers [10]. This means that the Dragon Runner can be deployed anywhere rescue workers can reach, which is a big advantage compared to a robot like the Thermite S1, which requires multiple people along with a vehicle to deploy.

Figure 4: QinetiQ Dragon Runner 10 [10]

Overall, tank robots have proven to be an effective design in the Rescue League and in the real world, as the many shapes and sizes they appear in provide multiple different advantages.

Table 1 (Robocup 2019):

Team:	Max Speed:	Weight:	Cost:	Size:	Placement:	Awards:
Hector Darmstadt [7]	0.6 m/s	25 kg	$4,000	0.6 x 0.42 x 0.6 m	Third place	Best-In-Class Mobility
ATR Team [8]	0.48 m/s	56 kg	$95,000	1.55 x 0.55 x 0.3 m	N/A	N/A

Rocker Arm Robot

The rocker arm design is one of the most researched designs, and there are many prototypes out there for this design. This design is similar to the tank drive in that it uses a track over the wheels which allows it to climb over small obstacles. However, this design also has a rocker arm which gives it extra mobility. The rocker arm is attached near the front wheel of the tank, and it is essentially an extension of the tank drive which can rotate on an axis. Rocker arm designs come with either two or four rocker arms. These designs are very effective at moving over large terrain, as the rocker arm gives them the ability to climb over obstacles with extra dexterity. The rocker arm can also be used for other things such as moving obstacles out of the way. Rocker arms are fairly simple to operate and only need two operators: one driving the robot, and one operating the rocker arm. Rocker arm designs are more complex than wheeled and tank robots, however, because they have an extra element of mobility added to them. This also tends to increase the costs as more motors and other parts are needed to create and power the rocker arm. The rocker arms on these robots add an extra weak point, as the joint that connects the rocker arm to the rest of the robot will not be as stable as the rest of the robot and is most likely to break off after a big impact. Rocker arm robots are by far the most popular in the Robocup Rescue league, and some examples of these robots are Shinobi and iRAP Sechzig's 2019 robots [11, 12]. These robots are great examples of well-designed rocker arm robots as they both were able to navigate terrain and complete objectives very successfully, earning them first and second place respectively along with mobility and dexterity awards. Shinobi's robot has an average weight despite being a larger robot. This combination allows for the main body of the robot, the tank portion, to be very large as the tread covers a large area. This aids the robot with moving over smaller rubble without getting caught, as the large tread is able to glide over these obstacles [11]. The four rocker arms on this robot give it great mobility. Despite the rocker arms each being much smaller than the main body, the rocker arms are still very powerful as they cover the weaknesses of the main tank body, which involve climbing over bigger obstacles. The rocker arms can adjust the angle at which they hit surfaces in order to gain a greater grip and climb easier. Additionally, this robot has great build quality as there are few openings and exposed wires where the robot could be damaged.

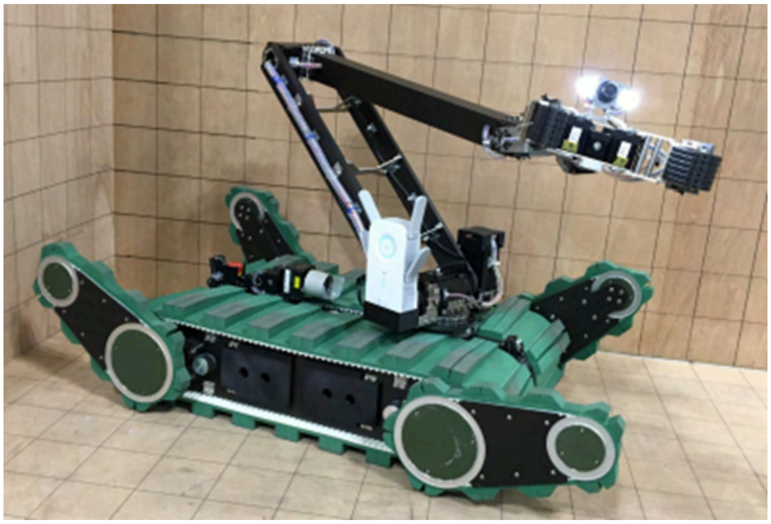

Figure 5: Shinobi 2019 robot [11]

iRAP Sechzig's rocker arm robot is very similar to Shinobi's. It also has four rocker arms which give it great mobility along with a large main body. However, this robot is much heavier at 77 kilograms, and this causes it to lose some dexterity as it is clunkier (Table 2). This would also be a drawback in a real-life situation as it would be much harder to deploy quickly by rescue workers. This design also features much larger rocker arms than Shinobi's robot, and this allows it to cover larger obstacles. There are also a few notable Search and Rescue robots outside of the Rescue League that use rocker arm designs. The iRobot 110 FirstLook is an ultra-mobile and lightweight rocker arm robot designed for Search and Rescue [13]. This robot weighs only 5 pounds, making it extremely easy to carry in hand or in a backpack. The robot is also extremely durable as it is designed to be thrown from a safe distance into dangerous areas that need to be searched. In order to allow for such a light design, this robot has a unique rocker arm that does not have any tread on it; instead, it is just a lever. The robot is able to use this lever to pull itself over obstacles and flip itself over, giving it extra mobility as well as the ability to right itself after big drops [13]. This robot design is far more durable than the robots in the Rescue League because it was built more securely in order to ensure it can survive being thrown from long distances. However, the lack of tread on the rocker arm means it has a harder time climbing obstacles, and the smaller rocker arm decreases the arm's effectiveness at pulling the robot over obstacles. These drawbacks come with the small design, and are necessary in order to achieve portability.

Figure 6: iRobot 110 FirstLook [13]

The iRobot 710 Kobra is another rocker arm Search and Rescue robot in the industry[14]. It is much bigger than the iRobot 110 FirstLook, and it is clearly not designed to be carried by hand as it weighs 367 pounds [14]. However, it includes a much bigger rocker arm that has tread, allowing it to climb bigger obstacles much easier. Additionally, it comes with a payload area for loading supplies and other necessities [14]. This feature is very useful as it can be used to send supplies to survivors once they are found. Rocker arm robots are a proven Search and Rescue robot design, as it is the most used in the Rescue League and is very common in the corporate world as well.

Figure 7: iRobot 710 Cobra [14]

Table 2 (Robocup 2019):

Team:	Max Speed:	Weight:	Cost:	Size:	Placement:	Awards:
iRAP SECHZIG [12]	2m/s	77kg	$23,000	0.6 x 1.2 x 0.6 m	Second place	Best-In-Class Mobility
SHINOBI [11]	2m/s	35kg	$32,700	1.0 x 0.5 x 1 m	First place	Best-In-Class Dexterity
NuBot [15]	2m/s	28.41kg	$37,000	0.6 x 0.6 x 0.5 m	N/A	N/A
MRL [16]	0.85m/s	95kg	$35,000	0.8 x 0.6 x 0.6 m	N/A	N/A
MARS-Rescue [17]	0.28m/s	4.2kg	$3,640	0.29 x 0.24 x 0.13 m	N/A	N/A

Table 3 (Robocup 2022):

Team:	Max Speed:	Weight:	Cost:	Size:	Placement:	Awards:
DYNAMICS [18]	1 m/s	65 kg	$27,500	0.8 x 0.5 x 0.4 m	N/A	N/A
Hector Darmstadt [19]	1.2 m/s	58 kg	$30,000	0.72 x 0.51 x 0.6 m	Second Place	Best-In-Class Autonomy

Wheeled Robot:

Wheeled robots are a classic design that is present in lots of robots. The standard wheel design includes either four or six wheels, with two or three on each side of the robot. For Search and Rescue robots, tires are used for the wheels since the flexibility of the rubber makes it easier to travel over rubble. Additionally, the tires come in very large sizes so that the robot can climb bigger obstacles while not getting the tires stuck in small spaces. Wheeled robots sometimes include suspensions for the wheels as well. Suspension allows for smoother travel over rough areas and makes the robot less susceptible to damage when moving fast over rough terrain. Wheeled robots come with many advantages because of its simple design. Firstly, wheeled robots tend to be very durable. Similar to tank robots, wheeled robots do not have many points of weakness because of their simple design. There are no joints in these robots, and the inflated tires combined with suspension provides a lot of cushion when landing from big falls. Another advantage is the portability of wheeled robots. Smaller wheeled robots are very easy to carry and hold in hand, making them easy to deploy. Even larger wheeled robots that can't be picked up can still be moved easily by pushing them and taking advantage of the rolling wheels. This means that larger robots can easily be moved into and out of transportation vehicles by just one or two people, and it can be done very quickly. One final advantage of wheeled robots is how easy it is to operate them. Wheeled robots are simple to operate because only one operator is needed, and the only controls are moving each set of wheels forward and backward, similar to the tank robot. This means that operators can be trained quickly and achieve a high level of accuracy. Wheeled robots also have some notable drawbacks that need to be addressed. The first drawback is the lack of grip wheels get on surfaces. Compared to tank and rocker arm robots, wheeled robots make a lot less contact with the ground because each tire only has a small section in contact with the ground. This means that the tires have a lot less grip on the ground, preventing them from climbing steep or slippery surfaces and obstacles bigger than the tires. An example of a notable wheeled robot in the Robocup Rescue League is XFinder's 2019 robot [20]. This robot features a four-wheel design, with two wheels on each side. The wheels have large tires along with a suspension system, allowing the robot to move over small obstacles easily. Additionally, the bottom of the robot is a good distance away from the ground, meaning it won't get caught over large bumps. These advantages allow the robot to climb over a variety of obstacles, including small stairs and bumpy terrain [20]. However, the robot suffers from the same weaknesses as other wheeled robots, as it does not generate much grip with the ground.

Figure 8: XFinder 2019 robot [20]

The Husky UGV is an example of a wheeled Search and Rescue robot in the industry, and it has a traditional wheeled robot design [21]. The Husky features a four wheel drivetrain with two wheels on each side. The tires are 13 inches in diameter, which allow the robot to easily traverse rough terrain. The size and build of the Husky is incredibly simple and compact, and it is built with durable materials, allowing it to survive any climate. The Husky's most unique feature, however, is its customizability. The Husky has many attachments that can be added to the robot, from movable claws to simple storage, which can be very useful in different Search and Rescue situations [21]. In general, wheeled robots tend to struggle with large obstacles and slippery surfaces because of the lack of grip wheels create. However, they also come with many advantages because of their durability and simplicity, making wheeled robots a viable design.

Figure 9: Husky UGV [21]

Table 4 (Robocup 2019):

Team:	Max Speed:	Weight:	Cost:	Size:	Placement	Awards:
XFinder [20]	0.8 m/s	85 kg	$4,000	1.0 x 0.6 x 0.78 m	N/A	N/A

Snake Robot

Snake Search and Rescue robot designs are some of the most unique, as they have a very unconventional design which solves prominent problems with other designs. Although snake robots come in many forms, there are some systems that are present in all types. Snake robots use multiple segments of moving parts to maneuver around obstacles and climb in tight spaces, similar to real snakes. Some advantages of snake robots are their ability to move through many different type of terrain. One of the snake robot design's greatest strengths is its ability to crawl through tight spaces. Snake robots are able to do this effectively because they can be made to be very thin, and the ability of each segment to twist and turn allows the robot to move through small passages easily. This flexibility also helps increase the surface area of the robot in contact with the ground, which helps with climbing a variety of obstacles as the robot has much more grip. The complexity of the snake robot design creates a lot of disadvantages. The segmented design creates a lot of different moving parts that need to work together in order for the robot to be functional. Additionally, snake robots involve a lot of different parts and have an unconventional style, making the building process more complicated. The multitude of joints between each section of the robot create lots of weak points. Finally, operating a snake robot is very difficult as it contains many degrees of freedom, meaning there are a lot more controls for an operator to manage.

Snake robots traditionally come in three different forms. The first is a segmented snake robot, which contains either wheeled or tank drive segments connected together. The second design relies mostly on joints to maneuver. This type of design does not have any wheels or tank to move itself, but instead relies on moving joints and therefore maneuvers similar to a real-life snake. The final snake robot design are soft snake robot designs. The body of these robots is made out of flexible materials that can easily change their shape, allowing for ultimate mobility through any space. Since most of these designs are still experimental and have not been put out for commercial use, statistics for these robots are unavailable. However, they can still be compared in categories such as maneuverability through large obstacles and small spaces, operability, and the usefulness of the unique abilities these robot designs have. One example of a segmented snake robot is the OmniTread OT4, which uses tank treads on each segment of the robot [22]. These tank segments are unique because they have treads on all four sides of the robot. This allows the robot to gain more grip in tight spaces where the sides and top of each segment come in contact with surfaces. The tank drive that is present on each segment gives it superior speed and traction compared to other designs. However, having treads on all four sides means the robot has to be fairly large in order to fit all of the systems, which can prevent the robot from fitting in very tight spaces.

Figure 10: OmniTread OT4 [22]

Robots that rely on joints to maneuver can solve this, as they can be built very small due to the lack of large subsystems. The Carnegie Mellon Snake robot is an example of a snake robot that uses joints to maneuver [23]. This robot is much thinner and more compact than all the other robot designs, allowing it to climb in small spaces. The Carnegie Mellon robot was tested in small steam pipes, where it was able to successfully maneuver around multiple bends and valves while sending back a video feed [23]. This snake robot design can be extremely useful in use cases like this, where traditional robots would not be able to fit and maneuver around the small pipes. However, this snake robot design would not be good at covering large distances, as it does not have the ability to travel fast or climb slippery surfaces.

Figure 11: Carnegie Mellon Snake Robot [23]

Soft snake robots are the final and most unique design. This design manipulates air, allowing it to expel air in order to squeeze in spaces and expand by pumping air in. The Vinebot from Stanford University is an example of a soft snake robot which uses flexible cylinders and air to traverse terrain [24]. This robot is able to squeeze through any space by controlling the air pressure inside its body, and can also move or lift heavy objects by expanding while underneath it. This provides a variety of use cases in search and rescue scenarios, and gives this robot a lot of potential. Tests with this robot showed it could move across sticky glue and nails, climb an icy wall, and navigate the space above a dropped ceiling. This robot has a similar weakness to the previous design, as it cannot reach very fast speeds with its slow crawl. It also is prone to damage from sharp objects, as any puncture will result in the pressure in the robot to be released. Overall, snake robots come in many different variations and have unique characteristics compared to the previously mentioned designs due to their flexibility. However, they are still very experimental, and will require a lot of work to be ready to be used in the field.

Figure 12: Stanford University Vinebot [24]

Conclusion:

Search and Rescue robots have come a long way, and there are many designs and prototypes that are ready to be used in the real world. However, determining which design is the most effective is much more complicated. Different situations call for various features that only certain designs have. However, a good way to compare these designs is by analyzing them in different categories where they would excel. These categories include durability, portability, maneuverability, cost, and complexity.

Robots that can survive large drops, impacts, and hazardous conditions are considered the most durable. Robot designs that avoid large and exposed joints and have minimal moving parts can excel in this category, as it reduces the number of areas where the robot could be damaged. Because of this, segmented snake robots, joint snake robots, and rocker arm robots are generally less durable. All of these designs rely on joints for mobility, creating weak points that are susceptible to damage after large falls. Between tank and wheeled robots, tank robots are more durable as they have tread protecting the drivetrain, while wheeled robots are susceptible to sharp objects that can puncture the tires or large divots in which tires can get stuck.

Portability is the next factor to consider for these robots. Portable robots are ones that can be transported and deployed easily in any situation. In order to achieve this, robots need to be lightweight, easily carried by one person, and deployable from a distance. Tank robots and soft snake robots can be lightweight, as they have many variations including large and small robots. Example of lightweight robots for these designs are the Stanford Vinebot and the QinetiQ's Dragon Runner 10. These robots are light due to the materials used, and they are small enough to easily be carried by a single individual. Rocker arm robots and tank robots are generally not lightweight because rocker arms add a significant amount of weight and size to the robot and the large wheels needed to climb obstacles make wheeled robots large and heavy as well. However, these two robots defer when it comes to deployment. In it current state, the vinebot can't easily be deployed from a distance, while the QinetiQ Dragon Runner 10 can be thrown into situations and can operate no matter which side it lands on. This makes tank robots in their current state the most portable. Soft snake robots obviously have lots of room to improve here, as these robots can also be designed to be thrown into situations or deployed from a distance due to their soft body being able to absorb impact. This is a common trend with snake robots in general, as these robots are relatively new and have a lot of potential.

Maneuverability is important in rescue situations where navigating terrain is a big factor. Robots that can manever through various obstacles will be able to search more effectively and will be less prone to getting stuck in a way which requires human assistance. Snake and rocker arm robots are the best in this category since they both have additional moving parts which allow them to navigate terrain. Rocker arm robots are better on rough and rocky terrain as they can use the rocker arm to get around terrain, while wheeled and tank robots do not have any moving parts to assist with this. Snake robots are best in tight caves or underground situations, as all three robot designs are slim and can easily make their way through narrow and twisty caverns. These two robots designs are best in these respective situations when it comes to maneuverabiltiy.

The cost of a search and rescue robot is important as it impacts various aspects of a search and rescue robot design. A high-costing robots will be more difficult to mass-produce, meaning it won't be as readily available. Additionally, it will also impact the usefulness of these robots, as a robot that is very expensive must be effective in order to make up for the price spent. Finding a good cost to effectiveness ratio is important in order to ensure search and rescue robots are actually used. Two factors that impact cost the most are the size and amount of expensive parts used in the robot. Expensive parts include things such as motors and other components which require a lot of money to make. Low costing robots, therefore, should be small in order to avoid using too much material and should be simplistic so that moving parts are not used too much. Because of this, robots that are large and have many joints, such as rocker arm robots, segmented snake robots, and jointed snake robots will often cost more than the other designs. Tank and wheeled robots are the cheapest options, as their simplicity allows for a very cheap manufacturing process. An example of an ideal cheap robot is the Hector Darmstadt 2019 robot from the Robot Rescue League. This robot features a very small size with minimal parts, allowing the cost to build to be reduced to just 4,000 dollars (Table 1). This cost was much less than almost every other robot in the competition by a wide margin. Additionally, the team decided to build a larger rocker arm robot in 2022, and the cost of this robot was 30,000 dollars, far more than their tank robot from 2019 (Table 2). This shows how size and simplicity are major factors in the cost of the robot, allowing small tank and wheeled robots to be the cheapest option.

Complexity is important for search and rescue robots because it determines how well a design can be perfected and is closely related to cost. A complex robot will often lead to a more difficult manufacturing process and higher costs. However, these robots can also have additional features that make them better search and rescue robots. Finding a balance with complexity is difficult, as both simple and complex robots can succeed in different ways. This can be seen when comparing simple and complex robot designs such as the tank and snake designs. The tank robot design can be very effective as seen with the Howe & Howe Thermite S1 and QinetiQ Dragon Runner 10. Both of these designs are fairly simple but are good enough to be used in the field. Snake robot designs are good examples of complex designs, as they are still in the early stages and will take more time and experimentation to become fully developed. Due to their complexity, only prototypes of this design have been made, and none are ready for use on the field. However, their unique and complex design gives it many unique advantages and use cases, such as navigating tight and winding caves. Since less complex robot designs are easier to perfect, they are generally preferred over complex robots which are more difficult to perfect and are not as useful in the present. Because of this, designs including tank and wheeled robots are the best in terms of complexity as they have minimal subsystems and other moving parts involved in their designs.

Analyzing these categories gives important takeaways about each robot design and their strengths. However, these categories have made it clear that no one design can excel in all of these categories. This makes it difficult to choose one design that is better than the rest and should be used for all search and rescue purposes. Instead, a better approach would be to narrow down the number of designs and assign certain designs to different situations in which they perform best. Firstly, wheeled robots can be eliminated since they do not excel in many categories. The only strengths of this robot design are its complexity, cost, and flat ground speed. The simplicity of the wheeled robot design means it can be perfected and made very easily, but it also means there is little room for improvement, which will lead the wheeled robot design to become outpaced by other designs in the future. The flat ground speed of a wheeled robot is not useful in most search and rescue situations, as the ground is rarely flat, and search and rescue scenarios with simple flat terrain would find more use with drones which can scan a larger area faster than a ground robot. Because of this, the wheeled robot design does not have many areas in which it excels. The snake robot design is a must-use design because of the unique situations in which it is useful. No other robot design is small and flexible enough to wiggle through tight passages and caves the way a snake robot can. Additionally, the snake robot is only in its earlies stages, and will be improved a lot over the next few years as designs such as the vinebot become more robust. These unique abilities mean the snake robot design must be used in any underground situation involving small passageways or caves. Finally, for above-ground rescue missions involving rough terrain and hazardous conditions, the rocker arm robots and tank robots stand out as the best options. Both utilize the same drivetrain which allows for a lot of grip due to the tread, which also protects the drivetrain from the environment. The rocker arm provides additional mobility while sacrificing durability. The tank robot has a more durable system, but is less mobile due to the lack of an extra joint. Between the two, the rocker arm robot is the better option for a few reasons. Firstly, the durability issue that comes with rocker arm robots is something that can be improved. As research continues, new ways to manufacture the rocker arm joint will allow the robot to become much more durable. However, the maneuverability issue that comes with the tank robot design can't be fixed without modifying the design as a whole. Because of this, the rocker arm robot design is the better options since its flaws are fixable. In conclusion, the rocker arm and snake robots are the best options, and they should be used in search and rescue situations together, as their strengths provide different advantages depending on the situation.

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