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Development of Robotic Rovers: A Review

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Abstract. The robotic rover is defined as a small vehicle that can move over rough ground and it is initially used by NASA for space exploration. However, this type of rover is expensive, using complicated and complex materials and software as well as large in size. Robotic rover fills the gap without endangering personnel involves in life-threatening condition or scenario that human sometimes needs to deal with. It can be considered to be deployed in assisting safety authorities to collect information and insights as well as work lift in search and rescue operations. In this paper, the progress that has been made towards the development of robotic rover which has been done in previous years are reviewed, including the design, functions, specifications, and applications, to meet requirements in performing a variety of tasks including hazardous identification, site surveillance and monitoring. Subsequent to this, a few analyses on the design and development of the proposed robotic rover are also discussed. The ultimate aim is to come out with such rover that is portable, small in size and low cost, together with user-friendly functions and specifications for future potential applications.

1. Introduction

Robotic systems have been developed to assist humans in various tasks and applications, either in industrial or domestic purposes. These systems are categorized into Unmanned Aerial Vehicles (UAV), Unmanned Ground Vehicle (UGV), Under Sea Vehicles (USV), space robots and medical robots [1, 2]. By having these systems, certain dangerous and incapable tasks could be done to replace humans mainly in monitoring, inspections, repairs, and maintenance at risks places such as nuclear plants, oil rigs, construction sites, and others. This paper discusses and reviews types of UGV particularly in its designs, features, and applications, which initially it was used for the planetary surface on a lander-style spacecraft [3]. Remote OVerhead Extendable Robot (ROVER) is actually a term for a small-scale robotic UGV that had been built by NASA for space exploration designed to move across the surface of a planet. The popular rovers developed by NASA are Spirit and Opportunity that have been commissioned in Mars explorations [4]. Other than that, agile prototypes named The Light-weight Rover Unit (LRU) had been developed for autonomous planetary exploration purposes with relatively small in size [5]. As the results of successful robotic missions on Moon and Mars, future plans have been made for carrying out various activities and experiments. There are various tasks need to be done by the rover especially for atmospheric aspects like data supervision about air pressure, temperature climate and temperature [6]. Besides this, a rover has other potential wide applications in the real world such as in scientific exploration, safety and weapon system endeavor as well as in military applications [7]. Developments of robotic rovers are usually designed based on specific requirements needed by the authorities. Most of the developed rovers are large, bulky and take a lot of spaces to store, which are not suitable to be used in certain situations.

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For example, the rovers would be deployed in many dangerous situations where humans fear to tread. In specific, the rovers could be used by the Hazardous Materials Management (HAZMAT) authorities in conducting their responsibilities to save lives. For HAZMAT personnel, the most threatening risk can be occurred on first entry by the team because of the type of materials that they are dealing with might be unknown. Therefore, a robotic rover can be sent to assess, reduce or eliminate the risks in dangerous situations and prevent human life-threatening risks of death that may lurk with wrong moves [8]. Therefore, this paper discusses and reviews the developments that have been made in unmanned ground vehicles or rovers, especially on its designs and applications, as well as potential implementations in the future.

2. Development of designs in the existing rover

In 1985, a robot has been developed by researchers in the University of Tokyo called AMOOTY, which named by using the acronyms of six researchers of the robot [9]. The design of this robot is shown in Figure 1, with a look like an elephant trunk and able to climb staircases. The researchers of this robot conducted research on the concept of maintenance in a nuclear reactor and came up with a locomotion system and nine degrees of freedom (DOF) for the robot arm. This work was an outstanding achievement whereby that time a robotic arm has not existed in nature yet. However, this robot still has many problems to be solved such as the speed is too slow because it is heavy and in bulky size which makes it hard to move around [10]. Another rover was developed under the Emergency Response Robotics project by Jet Propulsion Laboratory in 1991. As shown in Figure 2, this rover is a remote mobile robot named Andros for the deployment by the HAZMAT team [11]. By using this robot, the team had conducted several testing and trainings to determine other requirements needed by the HAZMAT team in order to use this robot in their missions efficiently.

Figure 1. AMOOTY [9]

The Andros robot was redesigned by adding other requirements such as track modifications and specialized key tools. Modification on the track was done by articulating front and rear sections of the robot for climbing stairs. Then, specialized key tools were developed to enable the robot in unlocking doors. Besides that, a winch system was added as an aid for the robot in opening doors. Based on these modifications highlighted by the HAZMAT team, the robot was renamed as HAZBOT II [12], as shown in Figure 3 (a). HAZBOT is also specifically known as Ground Emergency Response Vehicle, a type of UGV that is used only during emergency situations.

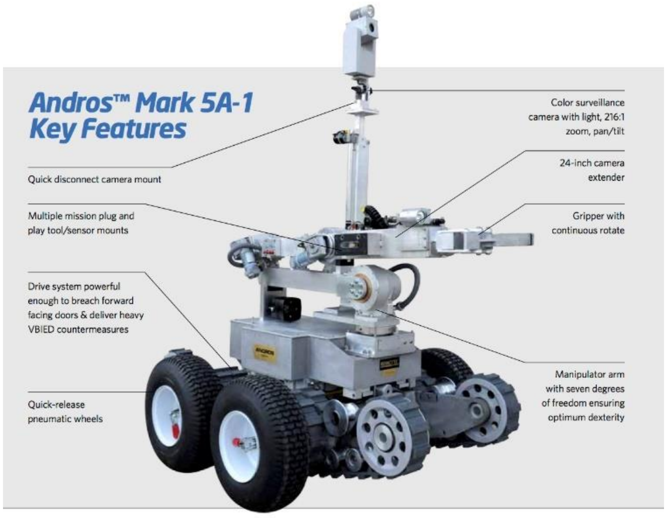
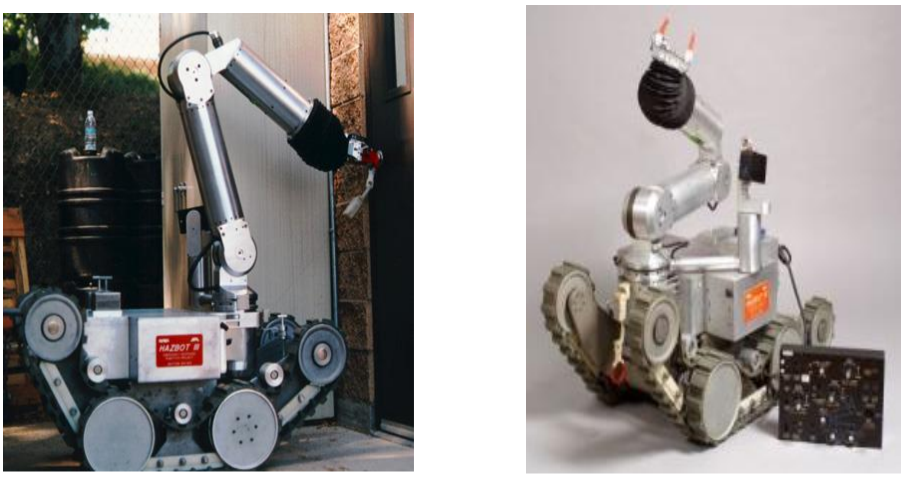


Figure 2. ANDROS robot [11]



(a) (b)

Figure 3. (a) HAZBOT II and (b) HAZBOT III [12]

However, the researchers found drawbacks in the design of HAZBOT II such as its dependent on the current configuration of manipulator at the operator control panel. Therefore, they decided to alter and redesign the robot in order to be operated in potential combustible atmospheres [13]. It needed to be redesigned with a smooth profile to ease the decontamination process if it is considered to be deployed in handling chemical gases [14]. In addition, the researchers were also considering to improve the speed of the robot and dexterity of the manipulator. The researchers have focused on implementing these modifications that led to the development of HAZBOT III, as shown in Figure 3(b).

Although HAZBOT III is the latest modification from the Jet Propulsion Laboratory (JPL) team members, they emphasized that there are four main factors need to be considered by designers in designing a rover for the future recommendations; robot speed, robot size, operator interface, and depth perception. As we knew, these emergency response robots are frequently exposed to the chemical gases and conduct operations such as unlocking doors, opening doors, and climbing stairs. It is, therefore, dexterity is very essential because these robots play the role to access the site at least less than an hour to collect information before the entry team is ready to go in [15]. Next, the size of the HAZBOT systems are too big and bulky, making them difficult to pass through doors and the robot arm is not required in most mission tasks. The development of the robot interface should be made very informative to provide the information required by the operator of the robot. By having all important information while operating the robot, it will help the operator of the robot to make decisions under critical circumstances. The improvement in depth perception is also needed to overcome the issue that the viewers faced difficulties when they have to view with a single video camera. Therefore, adding a simple depth cueing devices is the desirable solution.

There were few other robots were designed but for commercial value purposes such as LT2/F "Bulldog", as shown in Figure 4(a). This robot has many similar functions with previous HAZBOT II which it can open doors and maneuvers inside the house and its also equipped with various manipulator attachments to open doors. The specialty for this type of rover is that the arm can be equipped with a mount for a Carbon Fire 10 Disrupter. The supplier claimed that they can supply the disrupter mount with or without the disrupter to Explosive Ordinance Disposal (EOD) Departments. Hazardous device technicians used Explosive Ordinance Disposal (EOD) disrupters to neutralize explosive devices from a safe place [16]. The company which sells LT2 also designed a heavy-duty robot called HD2-s, as shown in Figure 4(b).

(a) (b)

Figure 4. (a) LT2/F "Bulldog" and (b) HD2-s [16]

The development of UGV design intended for the use by authorities such as anti-terrorism and police. It commonly consists of mobility platform equipped with sensors and computer software, power system and additional features which are depending on the scope of the tasks to be conducted by the rover [17]. As an example, the SR-10 Inspector is equipped with crawler drive which makes the robot moves under various terrain conditions and also able to climb stairs with maximum speed beyond 16 km/h. Besides that, the sensors play a very important role to assist the robot to avoid collision and define the distance from the wall [18].

The ground robotic system [19] such as Teodor Robot as shown in Figure 5, is equipped with an array of metal detectors. It helps the robot to detect smaller anti-personal mines. Besides that, the chassis of Teodor is equipped with an extensive sensor arsenal [20], [21]. Teodor is known as search and rescue robot, so it really needs navigation assistance such as a real-time 3D laser mapping system [22], a real-time time-of-flight camera [23] and a real-time stereo vision system [24]. By implementing all these systems, it will ease search and rescue operations [24, 25] because of the robot itself capable to conduct autonomous navigation [26].

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Figure 5. Teodor [22]

Based on all the models that had been reviewed, new inventions of the smart robotic rover was invented to meet the authorities' requirements. Every component and part of the product is designed and drawn with the precise dimension as the real product. Figure 6 shows the isometric view for the final design of robotic rover. The proposed rover consists of a robotic arm, gripper, track, chassis, DC motor, vision system, and controller.

The specification of the developed rover is explained in Table 1 [27]. The rover is considered lightweight and small in size even equipped with a robot arm, gripper, and camera system. This rover has a portable ground system to receive images from the camera installed on the rover. An experiment had been conducted on its ability to lift object where the robot arm with gripper can be lifted between 0.483 meters to 0.013 meters, as shown in Figure 7. This rover could lift small items such as a pen marker and a small aerosol spray that has weight around 750 gram, as shown in Figure 8 [28]. The robotic arm can also be moved in transverse motion but it needs to be modified by adding an additional degree of freedom (DOF) to make the motion of the arm more stable. The gripper attached at the end of the robot arm can be rotated in 360 degrees either in a clockwise or counter clockwise direction. This rover is connected to a joystick to control the movement of the rover as well as the robotic arm and gripper.

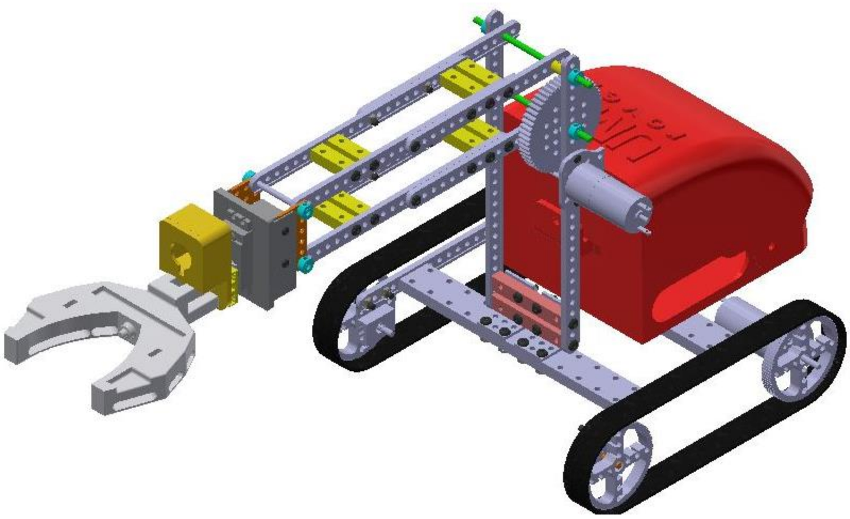

Figure 6. Robotic Rover

Table 1. Specifications of robotic rover

Specification	Description
Speed	Up to 5.8 mph (9.3 kph)
Dimension (Height x Width x Length)	216.06 mm × 132.99 mm × 264.67 mm
Weight	2.2 kg (rover), 3.0 kg (ground station)
Height of robotic arm	0.483 m (max), 0.013 m (min)

3. Applications of rover

This section reviews the applications of the rovers in the nuclear industry as well as search and rescue operations. Nuclear energy industries created dangerous environments that risk human if any casualties happen. As an alternative, robots are sent to access toxic and combustible atmospheres in nuclear plants. The robots or rovers that are deployed to this application are designed to detect nuclear radiation and air samples, as well as to conduct mechanical tasks in such circumstances. Robotic systems could be considered as the best solution to represent human in obtaining data from dangerous conditions in nuclear plants. Based on the literature [1], the rovers have been deployed in several nuclear plants such as at Three Mile Island Unit-2 plant in the USA, the Chernobyl plant in Ukraine, Tokaimura and Fukushima Daiichi plants in Japan. This literature also listed the details of the robots with its specifications related to previous references.

Besides that**,** the rovers were also used for Urban Search and Rescue (USAR) activities [29], [30]. The developed mobile robots should be robust in design and equipped with various functionality for survival during disasters. However, current rovers are still not ready to be deployed in different environments and they are deterred by narrow passages and wreckage. Even though there are many difficulties to conduct research related to this study, but the researchers still trying to find solutions especially urban search rescue and hazardous prevention in large-scale earthquakes and other types of disasters [31],[32]. The development of rover in search and rescue operation can be review in Table 2.

Table 2. Application of rovers in search and rescue operations

Location	Robot)	Operating area	Locomotion	Terrain	Develop ed yaer)	Ref
Defense Advanced Research Projects Agency (DARPA)	Inuktun micro-Tracs VGTV	Pile	Tracked	steep inclines/ Declines in piping system	1989	[33]
	Micro-Tracs	Pile	Tracked		1989	[34]
	Foster-Miller Solem	Pile	Tracked	Rough/slight slopes/obstacles	2001	
	Talon	Pile	Tracked		2000	

4. Conclusions

Initially, rovers were used to replace man in space exploration. However, based on works of literature that have been reviewed in this paper, it can be also considered to be deployed in commercial applications such as site monitoring for several industries, search and rescue operations as well as conducting mechanical tasks using robotic arms and gripper attached to the rover. The goal of this paper is to analyze the specifications and features from existing rovers in order to invent simpler rover in terms of its system and manufacturing. In future work, we are planning to design more robust robotic rover for work lift, monitoring and safety purposes with robotic arm and gripper to collect and remove loads. Thorough analysis is required in achieving these aims, starting from designing, fabrication, material analysis as well as electrical aspects in order to manufacture this type of UGV in realization. Moreover, it could be considered to be used in monitoring situations during hazardous conditions or surveillance. By having this rover, it can reduce or eliminate risk to human life because it can be remotely controlled by using camera vision system and controller as what had been done by Teodor robot and robotic rover shown in Figure 6. Taking suggestions from recommendations of the HAZMAT teams, it is desirable to include additional features to the robotic rover such as gas detector, thermal camera, and rocker boogie track. The gas detector is suggested to be used for detection of toxic gases which are dangerous to humans in long exposure such as Carbon Monoxide (CO), Oxygen (O_2), Hydrogen Sulfide (H_2S), and other combustible gases which its concentration in air is defined as the Lower Explosive Limit (LEL). For example, if a gas is detected, electrodes on the LEL detector will send signals to alarms and can give indications for such gas levels between 0-100%. Thermal imaging on the rover would help to improve visibility in a dark environment during certain operations by detecting objects using infrared and creating an image based on that information. Movement of the rover also has to give attention and it is preferable if the rover could climb stairs and move on any type of land surfaces.

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