A Design of a Modular Mobile Robot for Rescue Operations

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Abstract

Modular robotics is one of the subfields of mobile robotics, which is emerging as a new trend in various sectors. Modular mobile robots can be reconfigured to perform a wide variety of tasks. In this paper, applications of modular mobile robots in various sectors such as industry, space, surgery, rescue and entertainment tasks are discussed. Based on the study, an improved design of a modular mobile robot for navigating through different terrains during a rescue operation is presented. Simulation study of the robot is included to demonstrate a motion capability of the modular mobile robot.

Keywords: Modular robots, Applications of modular robots, Design, Simulation study

1. Introduction

Robots were known to assist people in a wide variety of tasks such as industrial [1], [2] household [3], rescue [4], [5], medical [6], [7] space [8], defense [9], and entertainment [10] fields. The emergence of artificial intelligence elevated a performance of robots [11]. Most industrial operations are currently performed by robotic systems due to its better performance capabilities compared to human operators. Robots are proved to be more precise and accurate in carrying out a task compared to human operators. Employers are forced to build unmanned workplaces due to a variety of factors such as increasing wages, absence of skilled employees, dangerous work conditions, etc. Hence, most industries are replacing human operators with multi-tasking robotic systems. However, some of the challenging tasks inside industrial and service sectors are nowadays carried out in a collaboration mode. Such robots are known as collaborative robots [12].

Medical, service and space sectors have started to explore the capabilities of mobile robots [13]. The major reason is the multifunctional capabilities of mobile robots especially modular mobile robots. These kinds of robots can be controlled remotely to use in places or environments which are not accessible for a human operator to work. Service sectors are employing modular mobile robots to invigilate the conditions of patients and logistics tasks inside hospitals [14]. Modular robots are also used in space explorations and rescue operations. Ground and aerial modular robots are nowadays employed in places of natural calamities such as earth quakes [15], landslides and [16] and floods [17]. Modular robots can reach any location due to its shape shifting, flexible design and motion capabilities.

2. Applications of mobile and modular robot

Mobile manipulation combines the advantages of manipulation and navigation. Basiri *et al.* [18] developed a mobile robot with a UR5e [19] arm for performing activities in a construction field. The four-wheeled mobile platform was 78 cm long and 55 cm tall. The platform can support a payload of 25 kg. Bricks for construction purposes were identified and moved using a vision-based technique. Lio [20] was a service mobile robot developed as a care assistant to patients admitted in a hospital. It consisted of a 6 degrees-of-freedom (dof) arm and a mobile base with 4 wheels.

Mobile manipulators can be used in cooperative and collaborative tasks to compensate a growing demand for a workforce in industrial sectors. Robots in the industrial sector must follow safety regulations and have been proved to save a significant amount of time and money. Collaborative robots were developed for carrying out activities combinedly by human operators and robots in a shared configuration space [21]. A team of mobile manipulators used for carrying payload was presented in [22]. Each robot consisted of a 2 dof mobile base and a 2 dof planar arm for transferring an object from one place to another. Another set of mobile manipulators used for a collaborative 3D printing process was illustrated in [23]. Experimental validation proved that using collaborative robots increased a performance of a collaborative task.

Modular robots can perform a variety of tasks and adapt to the environment quickly. Connect-R [24] was a modular robot developed for implementing in an industrial environment. Each module has the ability to rotate around other modules, link to other modules, and extend based on the available space. A reconfigurable modular robot named Deformable Modular Robot (Datom) was presented in [25]. Each module of the robot was connected to other modules using a Face-centered cubic lattice pattern. The robot has a capability to separate from neighbouring modules during a task. FreeSN [26] was a modular reconfigurable robot consisted of strut and node modules. A node module was constructed using a low carbon steel spherical shell and a magnetic connector was used as a joining mechanism. SMORES-EP [27] was a modular robot used in construction sector. It can self-assemble to generate 3 different topologies based on a task. A docking control strategy was used for a successful docking of the robot. A self-reconfigurable mobile robot with 2 dof with a docking mechanism was demonstrated in [28]. It consisted of a hybrid mobile base with wheels and tracks. An image processing technique was used for locating a docking station for the charging of the modular robot.

Modular robots are also used in household and entertainment sectors. Roombots [29] were a group of modular robots designed to employ both as a payload carrier in houses and also act as toys for children. Roombots can act as adaptive and reconfigurable mobile robots and used for supporting furniture during relocation. The reconfigurable modular robot consisted of 12 modules with 36 dof. It can autonomously change shape, grasp, and move furniture. KAIRO-II, a modular robot developed for rescue operations was given in [30]. It consisted of 6 drive modules interconnected using 5 joint modules. KAIRO -II can ascend short stairs and steps shorter than 55 cm. Modular robots are more efficient in carrying out multiple tasks compared to mobile robots. Nowadays modular robots are used for navigating through different terrains using different modes of base motions. Unmanned ground and aerial modular mobile robots are used in rescue applications. These mobile robots can reach a specified location and invigilate the conditions of the environment using sensors attached to them. A design of a modular robot capable of navigating through uneven terrains was proposed in [31]. A hybrid wheel base for the robot was developed with both wheels and tracks. The robot consisted of a vertical translation unit, which was used for moving the robot in uneven terrains. Design of a homogenous modular robot consisted of revolute and prismatic joints was demonstrated in [32]. It consisted of a rotary plate docking mechanism that allows the robot to change configurations during a task.

Robots are used for carrying out surgeries and operations in the medical field. Versatile modular robotic arms are used in robotic surgeries, which can be assembled and dissembled based on task requirements. Robotic capsules are used for carrying out an endoscopy to detect internal diseases. Cameras and biochemical sensors used in these devices can detect internal body issues. Numerous distinct terrestrial modular robotic systems are employed for carrying out space related tasks. However, due to extreme terrestrial conditions, only few robots have been in active employment currently. However, modular robots are preferred for space related tasks since a reconfigurable robot can carry out multiple tasks [33], [34]. Mobile modular robots have been also used in military operations to reach complex terrains [35].

3. Advantages of modular robots

Generally, the cost of a robot manufactured is directly proportional to the size of the robot due to material requirements. Due to the high cost of industrial robots, most of the industries are not able to employ such robots for execution of tasks. However, modular robots are compact and cost-effective in terms of their size and materials.

Capabilities of mobile robots available in current market are not adequate to carry out complex tasks. In comparison to mobile robots, modular robots are more effective and successful when dealing with emergency situations. Modular robots are employed for rescue operations and in narrow pathways, where normal sized mobile robots cannot navigate. Another major capability of a modular robot to transform the shapes and patterns of individual modules.

One of the most important requirements for accomplishing a logistics-related operation is the capability to provide required speed of navigation. The ordered item is anticipated to be delivered as soon as possible. Traditional mobile robots cannot traverse through complex terrains due to mobile base mechanism limitations. However, a modular robot can transform its shape and pattern to control speeds during navigations.

One of the major issues faced by mobile robots is the limited space for navigation. Modular robots are proved to be traversable through narrow and curved pathways without any difficulty. This is mostly due to their shape shifting capabilities and ability to adapt to different environments. Hence, modular robots can be employed remotely to reach disaster zones for monitoring situations.

4. A design of a mobile robot

A design process of a modular robot is very complex since modular robots must be able to shift shapes based on requirements. Specifications of a modular robot play a crucial role in completing a task successfully. A traditional modular robot has 2 or more modules based on the requirements. Multiple modules can be manipulated for shifting shapes and configuration of the robot. In some circumstances, each module of a modular robot can be operated as a single robot, with no connectivity to other modules.

In this paper, a design of a modular mobile robot, which can be used for search and rescue operations was presented. The specific design (Fig. 1) allowed the robot to enter areas inaccessible to human rescue operators. It can carry necessary equipment, medicines, and has capability to convey information to communicate with online remote operators. A modular robot with two modules each with 4 wheels was designed in Tinkercad software [36], which is significantly more simple in modelling and operating than popular Gazebo [37], [38] or Webots [39], [40] robotic simulators. The design of each module consisted of a mobile robot with 4 wheels. One module with 4 wheels can be moved above the other. An 8-wheeled single-decker vehicle can be created by lining up two distinct vehicles in a row with a rail system in between the wheels. Self-rotating pallets were used for rotating one module and placing it on top of another module. The two modules can also be used separately depending on the task requirements. In such cases, GPS technology is used to detect positions of each module and reach a location for docking.

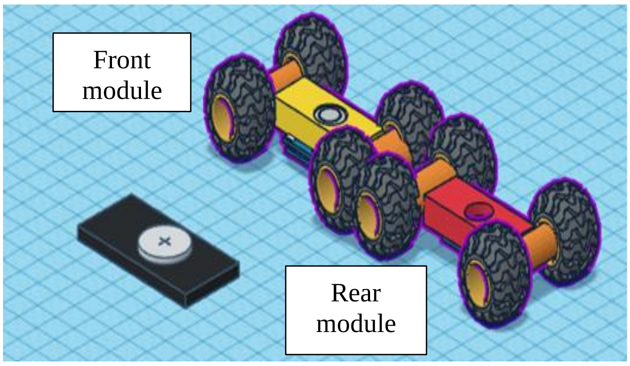

Fig. 1 Modular mobile robot with 2 modules

Each module of the robot consisted of a hydrogen fuel battery, a Raspberry PI 4 as processor and a WIFI module (Fig, 2). The batteries presented in the robot were charged using a coil. Raspberry PI 4 was used to control an overall process of the modular mobile robot. WIFI module was used for receiving and sending information. The robot was charged using a wireless charging method also. A rectifier and a filter were equipped inside the robot to manipulate incoming and outgoing currents. Magnetic resonance technique can also be used for charging the robot.

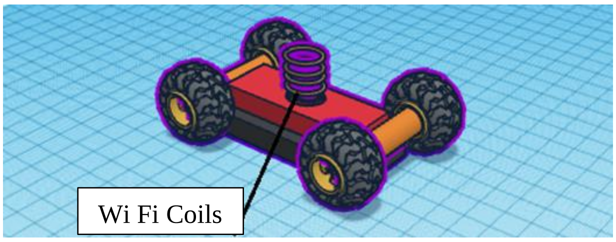

Fig. 2 WIFI equipped on modular robot

5. Simulation study

A simulation study was conducted for analysing motion capabilities of the modular robot. A task was assigned to the robot to reach a goal location from an initial location in a stacked configuration. The initial configuration of the modular robot is shown in Fig. 1. The rear module of the modular robot was sliding on to the top of front module using the wheel rotations as shown in Fig. 3. The final configuration of the robot when rear module reached the top of front module is shown in Fig. 4. The rear module can revert back to its initial pose using the same motion shown in the Fig. 4. The designed modular robot can be traversed using 8 wheels or 4 wheels by keeping rear module on the top based on the space constraints.

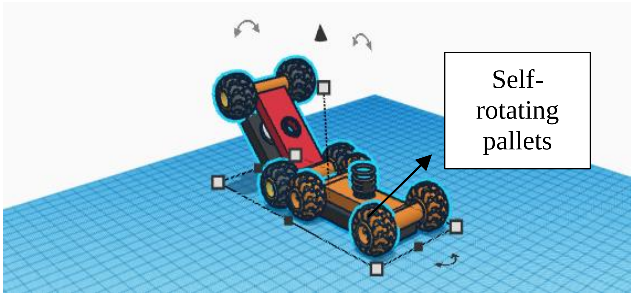

Fig. 3 Intermediate position of rear and front modules

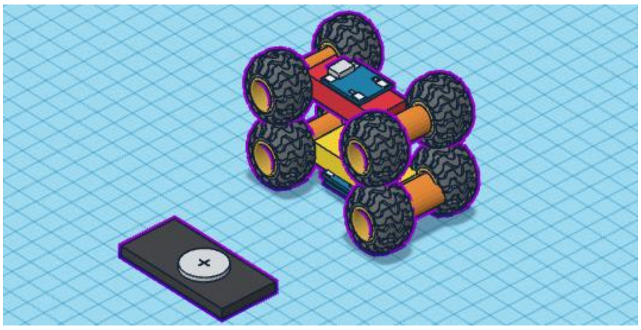

Fig. 4 Stacked configuration of the modular robot

The modular robot was able to reach the goal location in a stacked configuration. The motion of the robot was smooth on a flat terrain.

6. Conclusion

In this paper, applications and advantages of available designs of modular robots in various sectors were reviewed. Based on the study, a design of a modular robot with two modules was introduced. The modules can traverse individually or in combined pattern based on the space constraints and assigned tasks. A simulation study was carried out to analyze a motion capability of the designed modular robot. The nature of motion obtained was smooth and able to complete the task within limited time period. The motion capabilities of the designed modular robot in complex terrains and 3D spaces will be analyzed in future works. The energy capacity of the modular robot will be analyzed during a task for determining the operation runtime of the robot.

Acknowledgements

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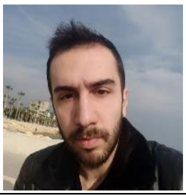

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