Journal of Modern Science and Technology
Vol. 4. No. 1. September 2016 Issue. Pp. 27 – 35

Urban Search and Rescue Mission: The Use of Marsupial Robots

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Marsupial animals are a group of mammals where the mother carries around its babies in a pouch (for example, kangaroos). Inspired by this idea from nature, the concept of marsupial robots is developed. We present a system that consists of a multi-terrain "mother robot" and smaller versatile "baby robots". The mother robot would carry in its interior the baby robots through a treacherous and rugged terrain to a central rescue location, while providing rapid, efficient and sheltered transportation. The baby robots can then come out and start urban search and rescue operation by locating and helping people from a collapsed or damaged structure, where it is risky for humans or rescue dogs to enter. Once the job of delivering the baby robots is complete, the mother robot acts as a "base station". It also has the task of transporting the baby robots back to safety after the search and rescue operation is complete. This paper presents a design of a mother robot and baby robot, suitable for urban search and rescue mission.

Keywords: marsupial robots; urban search and rescue; multi-terrain robot; wheeled mobile robots.

Field of Research: Robotics

1. Introduction

Multi-robot systems allow robots to divide and conquer the goal they are aiming to achieve. Such systems have the capability to demonstrate more efficient performance as well as higher levels of robustness and adaptability than a single multi-tasking robot. Therefore, in a search and rescue mission where the rescuers have approximately 48 hours to rescue their victim alive as mentioned by Shah and Choset (2004), multi-robot systems have raised a lot of interest, for example Lou et al. (2011); Grayson (2014); Yue et al. (2011). One novel category of multi-robot system is known as the marsupial robotic system, inspired by the marsupial mammal, kangaroo. Here, a larger mother robot carries smaller baby robots in its interior. The objective is to use the big and powerful mother robot's navigation strength to do the menacing work of carrying the babies to the central rescue zone across treacherous and rugged terrain, while allowing the more critical work of searching remote locations for survivors to smaller, specialized robots. The ideally low-

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cost baby robots, if required, are dispensable, because, even if one or two might get lost or stuck in the disaster debris, the others will continue with their mission without any setback. Just like its biological counterpart, the mother robot can have a deeper connection with its babies than just being a transporter. It can also provide power, assistance and guidance. In this paper a marsupial robotic team is designed. It constitutes of a bigger manual mother robot, which can hold a maximum of six autonomous baby robots at any given time. To the best of our knowledge, the work presented in this paper is unique because we have designed a wheeled marsupial robotic system which is enhanced to work together with each other for search and rescue missions especially in the context of Bangladesh. The system is designed in such a way that it can be easily build using local resources and at an adequately low cost. Tailored to the disaster management scenario of Bangladesh, the proposed system can be easily injected into the current search and rescue infrastructure of the country. We believe that our study can greatly improve the use of robots for urban search and rescue, meaningfully assisting the firefighters and other rescue workers, saving time, energy, money and perhaps, lives.

The remainder of the paper is presented as follows. Section 2 provides a discussion on existing literature. In Section 3, the system design of robots is described, followed by an explanation of the docking method in Section 4. Section 5 presents a prototype and its cost analysis; section 6 concludes the paper ending with an epilogue on future directions.

2. Literature Review

The usage of robots in search and rescue is an established concept in the field of robotics research, with numerous works of different varies of robots (land, air, water) existing in literature. We thus focus on the literature review of marsupial robots, which is less ubiquitous. There has been some work in the last decade on robot systems that can be termed as marsupial (i.e., a group of heterogeneous robots where one type transports the other). The mother robot of a marsupial robotic team, the Silver Bullet by Murphy et al. (1999), a chassis of a children's jeep can hold one shape-shifting Bujold, the baby robot, in 'flat position'. The Georgia Tech Yellow Jackets team of Dellaert et al. (2002) in the AAAI 2002 Urban Search and Rescue (USAR) competition used both manually operated iRobot ATRV-Mini as the mother robot which could carry four Sony Aibos legged robots on an open platform in the back. They used a laser range scanner to map the disaster arena and an omni-directional camera as eye for the operator. The smaller legged Aibos with color video camera brought more versatility for mobility in the rescue arena. Zhao et al. (2014) designed a mother robot with two motors using a wheel-track combo for locomotion. It contains a dual-floor docking station with a lifting platform and camera. It has a dimension of 67cm by 57cm by 40cm. Another team, Rybski et al. (2003), tested the miniature 200g Scout Robots, which are 11cm long and 4 cm in diameter. Although suitable for some situations, they were not quite successful in overcoming debris and holes and their low height meant poor camera angles. To assist fire fighters a 'system of systems' marsupial robots with a mother robot and three juvenile robots were assessed by Ngo et al. (2014). The 40kg Kohga3 robot from Toto (2015) is a rescue mini robot which was used to investigate collapsed buildings. This robot can climb over stairs and angles up to 45 degrees. Another suitable rescue robot is the agile Quince by Guizzo (2015). It has tracked wheels and is capable of driving over rubbles and climbing stairs.

In all of the above robot designs, the robots are either working alone or have a team which is not optimizing the marsupial mechanism for search and rescue operation. In contrast, our system actually encompasses the essence of a marsupial mother-baby team where the mother not only carries the baby but also maintains some sort of connection to the baby when it is away from the mother.

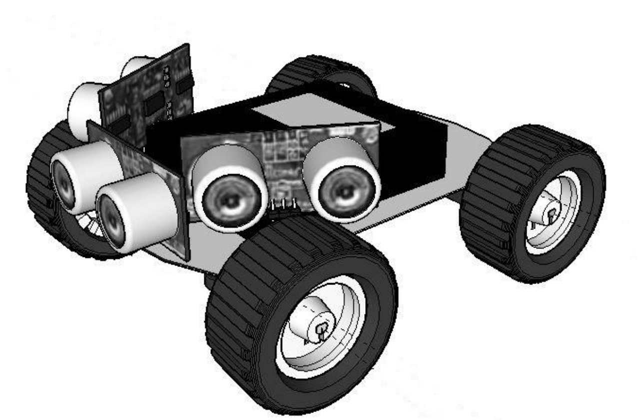
3. System Design

In the aftermath of a disaster like a building collapse, earthquake or tornado, urban search and rescue becomes a task of extreme urgency. Not only the valuable time for rescuing the victims safely is very limited but the fragile rescue area is unsafe for both rescuers and victims. A group of suitable robots with good teamwork and mobility can go a long way to saving the lives of survivors, as well ease the work of the rescuers. In our proposed system, the duty of the baby robot is to search and identify survivors across delicate zones and deliver them with small pack of food, simple tools for assistance and first aid and, most importantly pass on the location of a survivor to rescuers via the mother robot. The main design goals are to make the baby robot light and small so that it doesn't damage the fragile and wrecked areas. It also has to be able to easily drive over small obstacles and uneven terrains. Good networks of range sensors are also required for avoiding big obstacles when traversing the arena. And the cost of the baby robot is to be kept at a minimum, so that in case one or two of them fall into a crevice and get lost, it doesn't harm the mission or incur a high financial loss.

As just like in nature the mother is smarter, more powerful and bigger than its baby robots. The manual mother robot has to be powerful with good navigation ability and big enough to be able to carry six baby robots. A camera has to provide a good viewing angle for the rescue team to be able to drive the robot effectively.

A. Baby Robots

Figure 1: Design of the Baby Robot



The key features of the baby robots are described below:

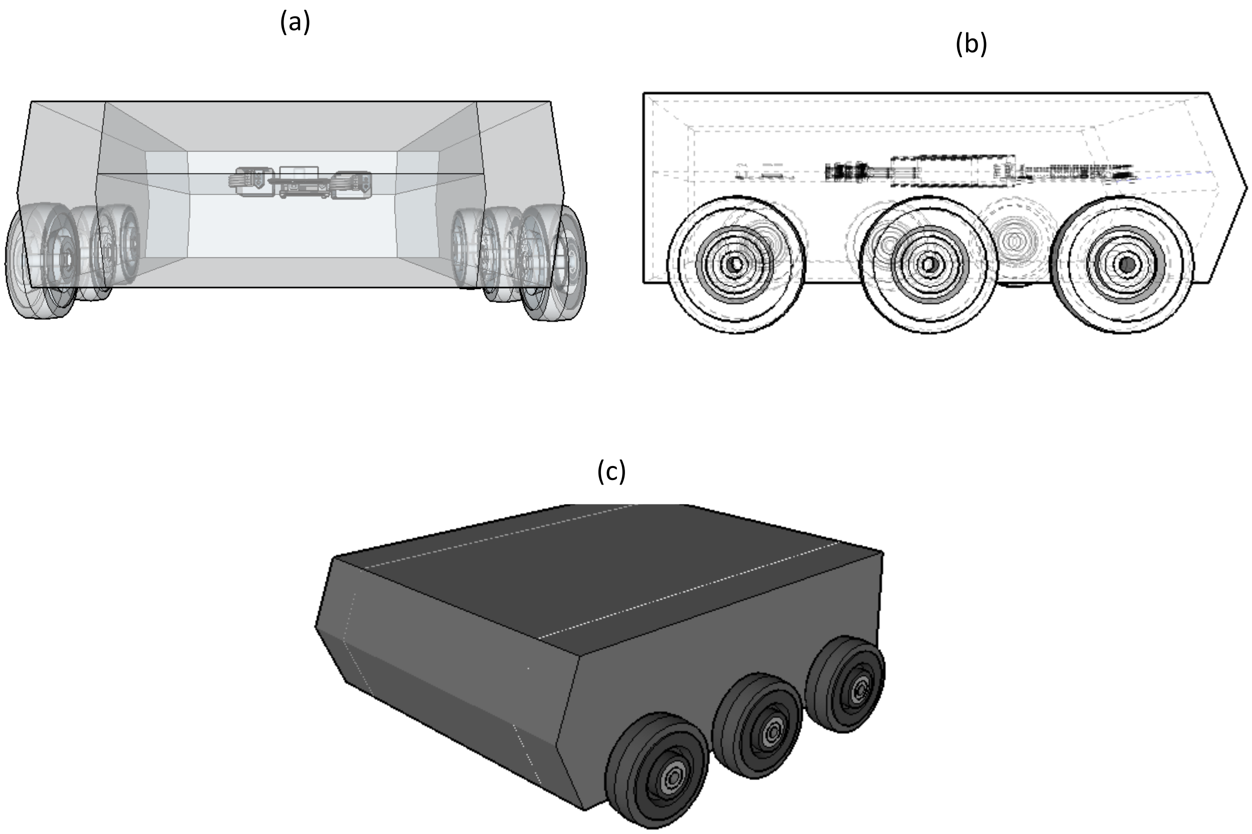
• The base of the baby robot is made using a printed circuit board. Since it has to travel over narrow fragile terrain, this robot is small in size, 12cm x 13cm x 6.5cm.
• The Brain of the baby robot is an ATmega328 chip which is placed in the PCB alongside the L293D motor driver IC.
• It contains four 600 rpm, 160 oz-in 6V DC micro metal gear motors. These motors are small and light. The 42mm diameter wheel has a 19mm rubber tire. The placement of the front wheels enables the robot to easily climb over any small objects. The motors are inverted and screwed at the bottom of the chassis, which gives the robot 3.5cm clearance from ground.
• The three HC-SR04 sonar sensors give the robot the vision and ability to smartly traverse the terrain.
• The low cost of Global Positioning System (GPS) receiver makes is an accurate and suitable method for keeping track of the placement of the robot at all times.
• Lithium Ion 2 cells, 7.4V batteries with 1500mAh current capacity is used for powering the system.

B. Mother Robot

The mother robot is a heavy-duty robot and the main support it provides to its babies are described below
• Transporter: It carries the babies to and from a central search and rescue location
• Manager: The mother robot sets the formation for the baby robots, so as to prevent more than one robot to spend time searching in the same area.
• Messenger: If any survivor is found the message is sent to the mother robot. The mother computes the position of the survivor and forwards it to the rescuers.

The interior of the mother robot is divided into four chambers. The two side chambers are for the placement of the motor. The upper tier contains the controller, batteries and all other required components. The bottom tier is the baby robot chamber. It contains enough space for carrying six baby robots. The material of choice for making the frame is steel because of its strength, toughness and weldability. It is therefore a suitable material for protecting the babies inside. However, steel is a conductor of electricity, so the circuit chamber has to be insulated using plastic for safety. It has a dimension of 40cm x 40cm x 12.5cm. Since the mother robot has to carry out a lot of complex task, a microprocessor board, Raspberry Pi is chosen here. It will be controlled manually using an RC remote control. Large 3.5' rubber wheels have been chosen for the robot to provide it with the ability to easily steer across and over multiple surfaces. High torque, high speed DC motors are required for the mother robot to give it the power to navigate effectively across all terrains.

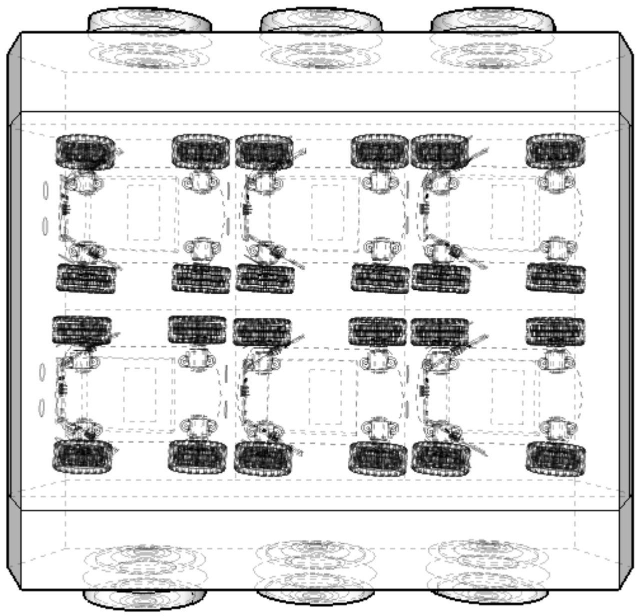
Figure 2: Isometric View, Front View and Side View of the Mother Robot



C. Team Work

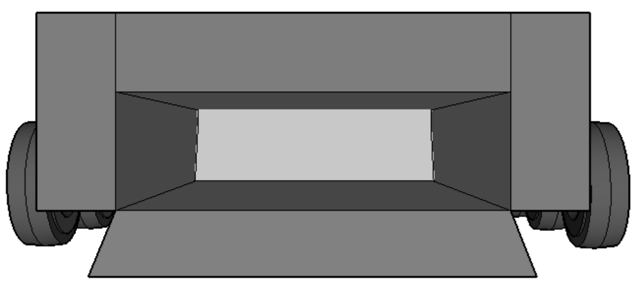
Figure 3 shows the mother robot containing six baby robots inside. The baby robots are very compact so as to minimize any calamity when the mother is transporting them through bumpy and menacing routes. Once the mother reaches its central goal location, it stations itself. Then the door of the mother robot opens and the six robots slide out. Once the mission is over, the baby robots come back in and maintain the same orientation inside the compact baby chamber.

Figure 3: The Baby Robots Placed Inside the Mother Robot



4. Docking Method of the Mother Robot

Figure 4: Docking Mechanism of the Mother Robot



Once the mother robot goes close enough to a rescue site or if it gets stuck anywhere, it has to deploy the baby robots. The door at the rear end of the robot is flipped open using servo motors. It then makes an angle of about 25 degrees with the ground, which is within reach of the robot to travel across.

After the mother robot docks, it works as a base station. A network mesh using nrf modules has to be set up, which would allow each baby robots to communicate individually with the mother robot. The mother robot maps the route for the whole mission. Moreover, the mother robot separately communicates with human rescuers. If any human survivor is found the data is processed and passed back on to the rescuers.

5. Implementation and Cost Analysis

Figure 5: A Prototype of the Baby Robot

A prototype of the baby robot is constructed and it is displayed in figure 5 below. The robot can easily ascend and angle of 30 degrees and it can also mount over obstacles of the size of the radius of its wheels, making the robot suitable for various terrains.

Table1: Cost Analysis of the Baby Robot Prototype

Product Description	**Quantity**	**Cost per unit (TK)**	**Cost (TK)**
Micro Metal Motor	4	550	2200
Wheel Pair	2	350	700
Motor Mount Pair	2	380	760
Ultrasonic Sensor	3	200	600
Arduino Uno	1	850	850
Motor Driver Shield	1	800	800
PCB board	1	150	150
Miscellaneous	-	250	250
Total			**6310**

The cost of the prototype of the baby robot is very low compared to other rescue robots. Although limited in its capabilities, it is optimized for urban search and rescue operation. The baby robots can be further customized with appropriate sensors depending on the nature of the operation it is going to perform. The bigger mother robot allows the baby robot to be specialized in a single task. The massive size and strength needed for navigation is taken care of by the mother robot.

6. Conclusion

This paper focuses on the design of a marsupial robotic system for urban search and rescue operation. The large powerful mother robot with good navigation prowess can transport six smaller baby robots on its interior. The manually controlled mother robot with a feedback camera transports the baby robots to the central rescue location. Its back door then tilts open and the six baby robots drive out of the mother robot. The baby robots are equipped with three simple sonar sensors to enable them to smartly traverse the arena. These are light robots with good mobility and are easily able to traverse across uneven, tunneled terrains. Most search and rescue robots are designed to be robust and versatile, with one big robot able to do a lot of tasks. The advantage of the multi-robot system in our research is that we can parallelize the search and rescue operation and during a disaster scenario, time is very critical. The marsupial method allows us to build small and cheap robots which can be designed to specialize in certain tasks only. In a disaster site, the small robots will allow us to search for survivors in dangerous and risky areas where it would be difficult for much bigger and heavier robots and even humans to travel. Having multiple robots mean that the weight of responsibility is shared between the robots. It would not matter if few robots get stuck or damaged, the other robots would still be able to continue the operation.

The use of marsupial robots for urban search and rescue operation has the potential to save plenty of lives. Such mechanism can bypass the design issues that many robots face with the uncertain terrain and surrounding of a rescue zone. Instead of having to design one complex robot that can do it all, responsibilities can be shared by the robots. Our future work will be on building a prototype of the mother robot, setting up the communication network and ultimately build a ready-to-deploy system that can be transported to any disaster site and put into work right away, aiding the human rescue works in saving lives.

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