Low- Cost Rescue Robot for Disaster Management In a Developing Country – Development of a Prototype Using Locally Available Technology

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Abstract. The use of robots in different fields is common and effective in developed countries. In case of incident management or emergency rescue after a disaster, robots are often used to lessen the human effort where it is either impossible or life-threatening for rescuers. Though developed countries can afford robotic-effort for pro-disaster management, the scenario is totally opposite for developing and under-developed countries to engage such a machine-help due to high cost of the machines and high maintenance cost as well. In this research paper, the authors proposed a low-cost "Rescue-Robot" for pro-disaster management which can overcome the budget-constraints as well as fully capable of rescue purposes for incident management. Here, all the research works were performed in Bangladesh – a developing country in South Asia. A disaster struck structure was chosen and a thorough survey was performed to understand the real-life environment for the prototype. The prototype was developed considering the results of this survey and it was manufactured using all locally available components and facilities.

Keywords: Rescue-robot, pro-disaster management, cost-effectiveness.

INTRODUCTION

Disaster causes can be classified into two main groups-natural and man-made. In the past, pro-disaster rescue work was performed by human where machine assistance was not effectively utilized as it was not improved enough. As the time passed, the unprecedented number and scales of natural and human-induced disasters has urged the emergency search and rescue community around the world to seek for newer, more effective equipment to enhance their efficiency. Rely on search dogs, camera mounted probes and human help is still considered as the assisting tools and technology for rescue as well as search purposes. But, with the advancement of science and technology, intelligent robots (i-robots) equipped with advanced sensors and detectors are attracting more and more attentions from researchers and rescuers. The developed countries though achieved the technology and went on production for rescue robots, in case of developing or underdeveloped countries, this advanced and intelligent assisting tool remains a dream to-date. The reason is mainly for the budget constraints- without the money, no research work is possible, and without the research work, no innovation is capable-ultimately the aim for rescue robot as a mass production becomes a latent hope. In this paper, the researchers tried to illustrate how to develop the technology of a rescue robot within a limited budget or low-cost in a developing country as well as effectiveness of reusable materials in making this rescue robot.

Background of the Research

Natural and human-induced disasters always cost in terms of money or lives. Natural disasters in recent years, such as the Hurricane Katrina and Rita in 2005, China earthquake in the capital of Sichuan in 2008, Cyclone Nargis in Burma and Bangladesh in 2008 and so others throughout the world claimed deadly and costly tolls to the affected communities [1]. Human-induced disasters in the form of civil-war, terrorist attacks etc. also have direct casualties not fewer than the natural disasters. Collapsed buildings are common field environment for humanitarian search and rescue operations. Earthquakes, typhoons, tornados, weaponry destructions, and catastrophic explosions can all generate damaged buildings in large scales. The use of heavy machinery in such incidents is prohibited because they would destabilize the structure, risking the lives of rescuers and victims buried in the rubble [2].

Figure 1: Actual site after the building collapsed in Dhaka, Bangladesh.

Rescue specialists use trained search dogs, cameras and listening devices to search for victims from above ground. Though search dogs are effective in finding human underground, they are unable to provide a general description of the physical environment the victim locates. Camera mounted probes can provide search specialists a visual image beyond voids that dogs can navigate through, however their effective range is no more than 4-6 meters along a straight line below ground surface [2]. Robot assisted search and rescue systems though took much attention from different perspective but the actual field work was started from 2001. The first real research on search and rescue robot began in the aftermath of the Oklahoma City bombing in 1995 [3]. Robots were not used at the bombing response, but suggestions as to how robots might have been applied were taken. In 2001, the first documented use of urban search and rescue robots took place during the 9/11 World Trade Center (WTC) disaster where mobile robots of different sizes and capacities were deployed. These robots range from tethered to wireless operated, and from the size of a lunch box to the size of a lawnmower [4].

The goal of this research project was to build a prototype of a robotic vehicle capable of working in the rescue process of some natural as well as human made disasters those generally occur in Bangladesh. According to the OFDA/CRED International Disaster Database, from 1942 to 1991, seven major wind storms caused the death of 570,413 people in Bangladesh [11]. Although earthquake did not claim life toll as wind storms but Ali et al. [12] explains that, the historical seismicity data of Bangladesh and adjoining areas indicate that Bangladesh is vulnerable to earthquake hazards. As Bangladesh is the world's most densely populated area, any future earthquake shall affect more people by unit area than any other seismically active regions of the world. So, taking into account principally these types of disasters where there may be destruction of structures, that may lead to confinement of human inside the debris, a disaster affected building was chosen to perform a survey on the environment that the prototype would have to face. Then the design procedure was performed basically concerning of the use of locally available and cost effective product and technology.

LITERATURE REVIEW

Hi-tech robots and related works have been done for last couple of years, but robots with high efficiency within a low cost budget may not gain that type of attention. In Johns Hopkins University, Baltimore, Maryland, four undergraduate engineering students designed and built a remote controlled robotic vehicle to find deadly land mines in rugged terrain and mark their location with a spray of paint. The student spent about $5000 to design and build their prototype. They estimated the vehicle could be mass-produced for $1,000 or less, not including the cost of more sophisticated detection sensors [6]. Educational robot like The Trikebot was claimed as a ground-up design effort chartered to develop an effective and low-cost educational robot for secondary level education and home use with its chassis to be produced economically (approximately $500 per chassis) by its inventors [7]. In India a team of students from the Sree Chithra College of Engineering, Pappanamcode, developed a low-cost working model of robot called "RASOR" capable of functioning in domestic and industrial environments. Though the team would not like to reveal the exact production cost of RASOR, "for marketing reasons", they said that making a RASOR would take less than Rs. 30,000 (approximately $615 USD) [8]. Albert Ko and Henry Y. K. Lau had worked for the low-cost autonomous robotic search and rescue system to design and cooperate in large quantity to search for survivors in rubbles. These robots were equipped with wireless communication module to facilitate data and video/audio transfer. These wireless robots, with no tethers, could navigate freely in obstructed environment but were difficult to track their locations once they wandered out of the operators' sights [2]. A team from the University of New South Wales, Sydney, Australia had built several "Redback" robots, each for a cost of approximately $4,500 USD including the cost of the onboard PC, batteries, communications and sensors [9]. Utilizing off-the-shelf low cost parts, Mundhenk et al. had constructed a robot that was small, light, powerful and relatively inexpensive (< $3900) [10]. From all these previous works, it is found that robots making with hi-technology and performance as well as low-cost budget sometimes cause hindrance to reach the goal. Our effort in this respect was to overcome all the previous failures as much as possible and to utilize reusable materials so as to negotiate with the budget limits.

METHODOLOGY

Field Work and Site Survey

On December 8, 2007, a 22 story high rise building (called RANGS Bhaban) in Dhaka, the capital of Bangladesh, collapsed while it was going on for demolition to make a link road. The casualties numbered more than 22. Dhaka, the capital of Bangladesh, is now one of the congested and mostly populated cities in the world with the population density 14,608/km[5]. With the population increase and urbanization, buildings are built for reasons, but in most cases without following proper guidelines and building codes. As a result, if a medium intensity of earthquake once strike Dhaka, the scenario will be disastrous. Keeping this fact in mind, a research work was carried out for the first time to make a machine help (hereinafter called rescue robot) for pro-disaster management and rescue purposes. The collapsed building site was investigated for getting the real life scenario after the disaster and also for the design purpose of the rescue robot to overcome all type of hindrance for rescue work.

Figure 2: Comparison of the gravel size on site with a pen.

The concrete structure building's 14^{th} floor collapsed due to improper demolition methods which caused the collapse of all the floors up to 4^{th} floor and took lives of several workers. The condition of the building was considered as quasi similar to a natural disaster struck building. A place was chosen on the 6^{th} floor that had the possibility of having someone trapped in. The survey results showed that for a beeline course for the robot, on an area having the length of 3 meters and width of 1 meter, the average length of concrete blocks (the length being in the same direction of the robot's path) came to be as 198 mm. In this measurement, concrete blocks having length of 50 mm to 300 mm were considered as potential obstacles for the robot. Blocks with length less than 50 mm were considered as too easy to overcome while those more than 300 mm were considered as too large that the robot could accommodate on it.

Similarly, the average height of the obstacles came as 106 mm and the average slope of the obstacle was measured as 60 degrees, that is, the robot would have to be capable of moving on the 60 degree slope to overcome that certain block.

These data were necessary to identify the size of the robot's wheels and also the overall dimensions of the total robot. This also helped to find the required torque for the drive motors.

Search for Local Components

After the completion of the robot's mechanical component design, a thorough investigation was performed on the availability of those components in the local market. The researchers had to rely on the reusable components wherever possible to imply. For example, aluminum chips collected from the lathe machine refusals were used to prepare the wheels of the robot. But because of the presence of too much slug, they did not appear to be a good choice for casting.

Figure 3: Aluminum chips for robot wheel.

Then aluminum alloy automobile engine cylinders were melted and casted which showed very good performance for the casting. These cylinders were collected from the junkyards. Custom tires were prepared from heavy duty timing belts. This would help the robot to move about in a very rough terrain.

Figure 4: Robot wheel before finishing.

DESIGN

Design for Work Environment

The work environment for a rescue robot differs from the conventional robots principally because of the rough terrain caused by the debris. This is similar to the international rescue robots competitions which require robots to negotiate complex and collapsed structures, find simulated victims, and generate human readable maps of the environment [13]. The wheel size was optimized considering the torque supplied by the motors and the average height of the obstacles obtained from the field survey. Four shock absorbers were made using metal spiral springs and steel plates. These were provided to minimize the shock created on the robot's body as well as the effect of a dislocated center of gravity that might have caused the risk of falling down of the robot while moving through an inclined surface or passing a large obstacle. Triangular brackets were provided in the chassis of the robot to induce extra strength to the structure. But aluminum was used wherever possible to keep the total weight of the robot down which is important for economic power consumption.

High torque worm-wheel motors (from surplus store) were used as drive and these were coupled to rear wheels. Each of the rear wheels was coupled to the front wheel by a chain-sprocket system to enhance the torque and work as a four wheel drive vehicle. This would help in its vigorous movement through the rough terrain and also to overcome obstacles.

Figure 5: Spring plate to resist bumping.

The tires of the wheels were made from heavy duty timing belts which had very good grip to move on an inclined surface. These had an additional property of heat resistance up to such a level which may help this robot perform rescue works in a hot, fire affected zone.

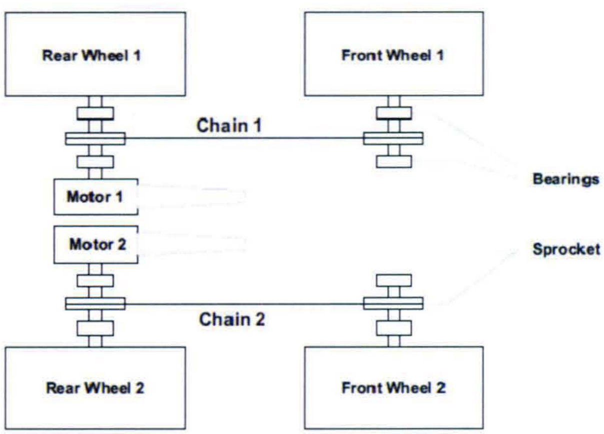

Figure 6: Schematic of the Robot's drive system.

Design for Manufacturability and Assembly

Some of the Design for Manufacturability (DFM) and Design for Assembly (DFA) methods were followed even though this was a prototype. This would help in the manufacturing and assembly of several robots if the prototype would work successfully. These techniques would in turns help reduce the labor and capital cost and also to keep the cost of the robot down.

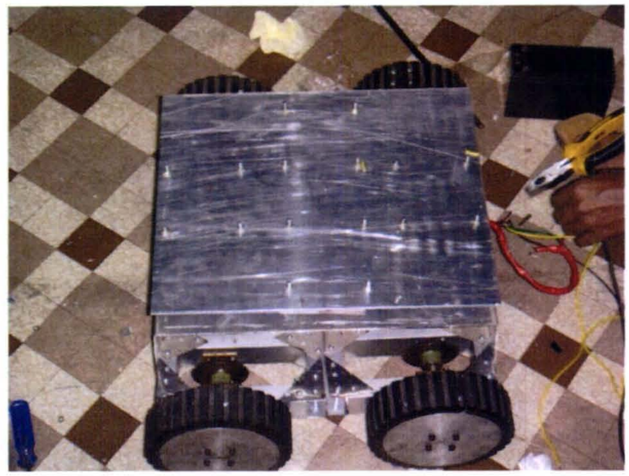

Figure 7: Rescuemate PDA (official name of the rescue robot).

Standardized parts were designed and used wherever possible. For example, standard sized screws were used in most of the parts of the assembly. The brackets and the aluminum channel stocks were interchangeable parts.

The whole chassis of the robot was composed of four symmetric and interchangeable sub-assemblies. Most of the screws were inserted as a top down manner. But in some cases the DFM and DFA were not possible to follow such as, parts count was tried best to minimize but to sacrifice for interchangeable and symmetric subassemblies, it increased to some extent. Secondary operations on the wheels were performed by machining the rough casted surface which also goes against DFM but this was important to reduce the material cost. If the wheels were manufactured from a large shaft then it would not only induce high cost for the material but also a large amount of aluminum would be wasted.

COST ANALYSIS

The cost can be divided into three broad categories as the cost for mechanical components, cost of manufacturing and the cost of the electronics and programming components.

Mechanical Components

These components shared a cost of around $550. The motors were collected from surplus stores which were still in very good working condition. These were power window motors of automobiles.

The chassis was made of mainly aluminum and these components were collected from the hardware stores which incurred a higher price. But the wheels were custom made from rejected aluminum alloy components from a junkyard. The chain sprockets were scrapped ship components.

Cost of Manufacturing

Most of the manufacturing works were performed in the university facility which included lathe and shaper machine operations, foundry and welding operations etc. and these were not counted to the cost of manufacturing. But for some special operations such as delicate welding or machining, local machine shops and the expert help was sought which took about only $100. This was possible as labor cost is very low in Bangladesh compared to any first world country.

Electronic Components

These components had two extremes. Some components were prepared in the lab as the simple circuit boards and wirings. But for some components the estimated cost was sacrificed for the high-tech components such as camera for the robot vision, high intensity search lights, microcontroller circuit boards, and radio frequency generating and receiving circuits giving clean signals. Although the robot's test run was performed by using very simple motor control circuit, these components were essential for the full fledged working for the rescue robot and so these costs were included in the estimation. These components shared a price of about $800.

Analyzing the costs, it can be concluded that the manufacturing cost and the cost for mechanical components were successfully kept low without affecting the quality much. The total cost including sophisticated sensor parts and some other costs were no more than $2,000.

RESULTS

From this research work, it is found that robotic assistance is quite important in Bangladesh for pro-disaster situation. In this three phase research work, the authors demonstrated the first phase whereas the second and third phases were still going on. The first phase was that a robot will be able to overcome all the difficulties to run in a disaster strike site where rubbles and other obstacles were by produced. In the second phase, it will be able to identify any live person/ living animal by its audio-visual system. The last and ultimate part is to attach a robotic arm with the vehicle so that it can assist the trapped person to rescue. The robotic arm has already prepared in the BUET mechanical engineering lab, but the on-site test is still to run. With a very low budget, the researchers/ authors were not only able to meet the research objectives but also made it possible how to use the scrap goods/materials to make a new robot. From this perspective, we can call this robot an "Environmental Friendly" rescue robot. During the initial test run of the robot, it showed good performance to overcome moderate sized discrete obstacles (maximum height being 55mm and on a plane surface having a slope up to 40°). But these performances need to be improved to achieve the goals set by the initial survey.

Limitations

There were some limitations like all other research works which the authors accept as of short funding and allocation of proper money in this project. The research work was carried out for only six months by the authors as they had to come to the USA for higher studies. But, before coming, they were able to complete the first phase which already have described. The micro-controller system was not completed for the first run of this robot. The robotic rescue arm was made by this time. The authors expect to contribute this kind of research work in the developing countries where the governments face budget constraints to do research work for making robotic rescue effort.

CONCLUSION AND FUTURE WORKS

Within a limited low-cost budget and reusable materials using, the Rescuemate PDA showed its effectiveness to match the research goals. For field test purpose, wire-connected experiments were done, but micro-processor control system was the research goal which is still under research options. Currently some works are going on for making it more affordable to the local agencies in Bangladesh in case of emergency rescue works. This was the first effort in Bangladesh to make a rescue robot from reusable materials and scrap goods. It is true that sometimes mass production can make anything available with low-cost, but the researchers at least tried to meet the need of rescue works by robotic effort within a low-budget in Bangladesh. In case of mass production, this type of robot can be built within $1000. In future, this current rescue version of robot in Bangladesh will get more rescue capability and preciseness because of the "Central Robotic Research (CRR)", the authors would like to contribute to this goal.

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