

Investigation of Incorporating an Unmanned Land Vehicle for Inspection in Manufacturing Environments

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Abstract

During rescue operations, rescuers are vulnerable as the infrastructure could be unstable and the environment could be harmful to them. An inspection method is needed to reduce or completely eliminate the exposure of human rescuers to possible dangers while assessing disasters/accidents. Research in search and rescue operations and the inspection on manufacturing environments, with the assistance of robots, has become a major topic with recent advancement in modern technology. This paper describes how an unmanned land robot (CAESAR V 2.0) can be used to inspect a disaster scene of a manufacturing setup. The physical properties of the robot which make it suitable for this task are discussed as well as the sensory equipment on board the robot which aid in the inspection of the dangerous environment.

Keywords

Unmanned Land Vehicle, Unstable Manufacturing Environments, Mechanical Structure

1 INTRODUCTION

Manufacturing involves the use of machines, tools and human labour to produce goods. In large factories, raw materials are transformed into finished goods on a large scale. Accidents occur quite often and their causes vary from human error, negligence, material/mechanical defects to those triggered by unexpected external forces. The scale of the accidents can be minor where there is little damage to goods and equipment or barely any injury to personnel. A larger scale can be severe where there is massive destruction of property and injury to personnel and fatalities. These may be considered as disasters. Disaster environments are characterised by harsh conditions such as unstable/collapsing infrastructure, harmful gases, fires, high temperatures, high humidity and poor visibility. These situations can be deemed dangerous for people to operate in or it would be physically impossible for the people to carry out operations. When disasters/accidents occur in a manufacturing environment, human rescuers can only enter the scene after it has been determined to be safe. Vital time is lost whilst assessing conditions externally or waiting for conditions to stabilize to levels that are safe. Thus people trapped in the disaster environment cannot get immediate help and are left stranded. As shown in figure 1 [1].

Robots are becoming important tools in search and rescue operations as well as inspection of unstable environments. Robots properly sized with suitable modularized and mechanized structure and well adapted to local conditions of unstructured and unknown environment can greatly improve safety and security of personnel as well as work efficiency, productivity and flexibility [2]. These robots could be first respondents at an accident scene and enter areas whose structural stability is unknown. The

robots can manoeuvre through rubble and hard to reach areas. They can collect valuable information about the disaster environment using sensors integrated on them and transmit it to human operators monitoring the situation from a safe location.



Figure 1 - Fire fighters extinguish a factory fire externally without immediate access to the internal environment

2 UNMANNED LAND VEHICLES

Unmanned land vehicles are vehicles/robots that operate while in contact with the ground and have no human presence on board. These robots have various uses which range from surveillance, hazardous material operation, bomb disposal, military operations to search and rescue operations. Their use in search and rescue operations is probably the most important. In recent times, they have been used to inspect disaster scenes. However, these robots encounter various problems which affect their performance. Robots that rushed to Ground Zero after September 11 attacks on the World Trade Centre towers to locate survivors

provided some hard lessons for their developers. Some of the tracked robots experienced debris ingestion, limiting their movement. Many of the robots were too big for the extremely small spaces left in the debris piles. Quite often robots would flip over and become stuck. Video was the main sensor used but due to dust and smoke at the site, the range of view was short. Communications with the robots were a challenge. Some of the robots used tethers which allowed for reliable control and full frame rate video but the tethers required extra support equipment and created snag points [3].

As a result of the problems faced at the World Trade Centre more effort has been put in the development of robots for search and rescue operations and better performing robots have been constructed such as the Packbot 510 and Quince robots shown in Figure 2 [4],[5]. These robots were deployed to the Fukushima Daiichi nuclear plant in Japan after a 7.4 magnitude quake devastated the region.



(a) Packbot 510

(b) Quince

Figure 2 - Robots used for inspection at the Fukushima Daiichi nuclear plant

CAESAR V 2.0 was developed at UKZN as an unmanned land vehicle, to assist in search and rescue operations and to inspect dangerous manufacturing environments. The robot was built to rectify problems encountered by previous robots during rescue operations. The robot's features which make it suitable for inspection of dangerous environments are explained below.

2.1 Mechanical structure

The physical structure of the robot is one of its most important features. It was required to withstand harsh conditions which human rescuers cannot survive in. The key features to take note of are the chassis, protective cover, traction system and flipper arms.

2.1.1 Chassis

The chassis is the frame that houses the various components of the robot. The chassis also supports the weight of internal components and absorbs the impact of collisions. A strong, light and sturdy design was required to ensure that the robot was stable and structurally secure enough to withstand the impact of collapsing walls and falling objects. Since the chassis encloses a large volume, the material used needed to be as light in weight as possible

whilst possessing considerable strength. The chassis was constructed from 2 mm thick 6063 Aluminium square tubing. This alloy has a very low density of 2.7 g/cm^3 as compared to mild steel which has a density of 7.85 g/cm^3 making it lighter in weight. The alloy also has a high tensile strength and high melting point of $600 \text{ }^\circ\text{C}$ thus ensuring the chassis will remain rigid when the robot enters fires or regions of high temperature.

2.1.2 Protective cover

The robot contains a variety of electrical and mechanical components that it uses for mobility and collection of data from the environment. These components need to be protected from possible harsh conditions which include falling debris, fires, water, high temperatures and corrosive gases. The cover needed to be light weight to minimise the overall weight of the robot. These hazards were considered in the design of the protective cover. The cover was constructed by producing a polystyrene mould which would cover the frame. Kelvar-Soric composite layers were then bonded on to the outside surface of the mould using phenolic resin. A final layer of aluminised material was then bonded using the phenolic resin to ensure flame resistance. An anti-flame mat was integrated on the inner surface of the polystyrene mould to reduce heat conductivity and increase flame resistance. Tests were carried out to determine the effectiveness of the protective cover to prevent heat penetration to internal components. The flame of a blow torch was applied to test pieces of the protective cover. It was found that the composite material, aluminised material and anti-flame mat all played a part in reducing heat penetration. Results from the tests showed that the surface temperature of the protective cover on the opposite side of the flame was reduced from $240 \text{ }^\circ\text{C}$ to $105 \text{ }^\circ\text{C}$ when exposed for 400 second to the flame.

2.1.3 Traction System

CAESAR V 2.0 is an unmanned ground vehicle and operates whilst in contact with the ground. During disasters/accidents, the surface which the robot has to navigate is generally irregular and uneven. High traction is required in order for it to negotiate obstacles without slipping. Slipping must be prevented to avoid getting stuck and also save energy (battery). There are three major categories of unmanned land vehicles in terms of locomotion systems, i.e. wheeled, tracked, and legged robots [6]. The simplest are wheeled robots, while tracked robots are used because of their ability to move on uneven terrains and they have higher traction. Tracks have a 30% greater pulling force as compared to wheels [7]. Legged robots can be the most manoeuvrable but due to their high degree of freedom; the number of actuators and sensors is relatively high which makes their dynamic analysis and modelling more complicated [6]. Due to the state of surfaces in disaster situations, tracks are desirable. Tracks for CAESAR V 2.0 were

constructed for the main drive with four flipper arms as shown in Figure 3. The tracks consist of roller chains with K-1 attachments. Traction pads are integrated on the K-1 attachments. The traction of the locomotion system is generated from friction between the traction pads and the surface on which it moves. The design and arrangement of the traction pads are therefore very important for movement of CAESAR V 2.0. The traction pads were made out of C-channel aluminium with Mold Max 60 polymer inside to enhance traction on smooth surfaces.

2.1.4 Flipper Arms

CAESAR V 2.0 has four flipper arms to enhance its mobility. High torque motors are responsible for rotation of the flipper arms and also to drive the tracks on the arms. The arms are capable of rotating 180° about the shaft they are attached to thus increasing the effectiveness of the flipper arms to assist in troublesome situations as seen in figure 3.

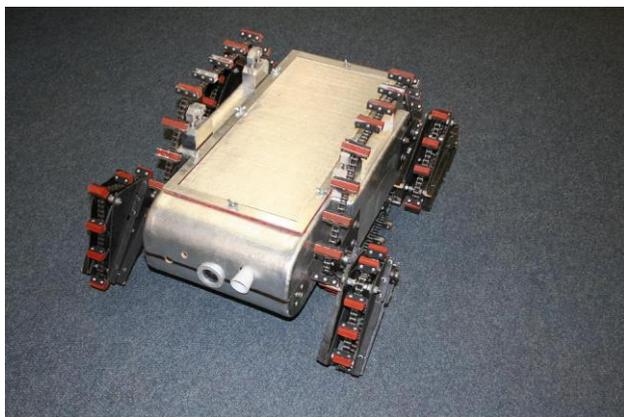


Figure 3 - CAESAR V 2.0 traction system

When the robot is exploring and inspecting the disaster/accident, it may encounter obstacles, steps and crevices which it cannot negotiate with the use of the main tracks alone. In this situation, the flipper arms rotate to an appropriate orientation and provide leverage. The rotation of the flipper arms is remotely controlled by the human operator but a semi-autonomous system is integrated to relieve the operator from deciding whether the obstacles in front of the robot are large enough for transformation to the required positions.

2.2 Sensors

In order to supply rescuers with information about the accident scene, CAESAR V 2.0 has on board it sensory equipment which are listed and explained below.

2.2.1 Gas sensors

In disaster situations there arises the possibility of harmful gases in the environment. The gases that are of primary importance in a search and rescue event are carbon dioxide, carbon monoxide, hydrogen sulphide, methane and oxygen [8]. These gases can be harmful to humans if they are at

certain concentrations. The gases need to be detected, analysed and then presented in a configuration useful to the rescuers. Figaro gas sensors are installed on board CAESAR V 2.0 to detect the concentration of these gases.

2.2.2 Temperature sensors

The temperature and in a disaster environment needs to be monitored to ensure that it is safe for the robot or human rescuers to carry out their operations. CAESAR V 2.0 has sensors for temperature detection incorporated.

2.2.3 Video and audio feed

Navigation of CAESAR V 2.0 is achieved by using visual images and audio signals sent by the robot. The robot has on board, a CMOS camera and a FLIR thermal imaging camera. The CMOS camera provides good video images in clear and reasonably lit environments whereas the thermal imaging camera is crucial in poorly lit environments with gases and smoke. The robot has a microphone to collect audio data from the scene and sends it to the operator. The operator is also able to transmit audio to the robot to communicate with victims.

2.3 Control station

The control of the robot is carried out at a safe location away from the disaster/accident scene. The setup of the control station is centred on the use of a laptop computer. Control of the robot is achieved by inputting the appropriate commands on the keyboard. A video game controller is also incorporated for ease of operation. The graphic user interface (GUI) provides an interface that the operator can observe the information received from the robot. Information received from sensors on board the robot is displayed on the GUI thus ensuring that the operator is aware of the conditions that the robot is operating in. The GUI also displays live video feed from the cameras on board which is vital for navigation.

A map of the disaster scene is generated and displayed in the GUI. The robot builds a map of its environment using video feed from the CMOS and thermal cameras. The simultaneous localisation and mapping (SLAM) method used to achieve this is Visual SLAM. This process is done by tracking image features between camera frames and determining the robot's pose and position of those features in the world based on their relative movement. The map is presented in the form of a point cloud which is a set vertices in a three dimensional coordinate system.

3 CAESAR V 2.0 FOR INSPECTION

The setup of CAESAR V 2.0 makes it suitable for inspecting manufacturing environments when accidents occur. The human operator will setup base at a safe location close to the accident scene. The operator will then control the robot to explore the disaster scene using the live video from the

cameras. As the robot travels, its sensors will collect information about the environment and send it to the control station via the WI-FI communication module for the operator to view as seen in figure 4. The mechanical structure of CAESAR V 2.0 gives it an advantage over other robots since all sensory equipment are enclosed in the chassis and protective cover hence navigation of unstable conditions is possible and inspection can continue after debris falls on the robot.

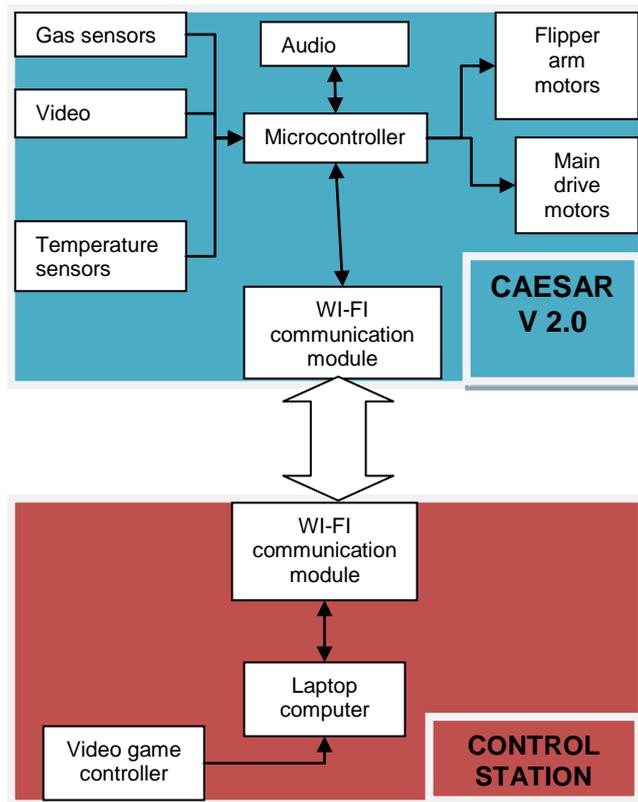


Figure 4 - Block diagram showing how rescuers use CAESAR V 2.0 to acquire information about disaster scene.

4 CONCLUSIONS

The problems encountered by rescuers during rescue and inspection operations have been given and explained. The importance of unmanned land vehicles in inspection and rescue operations of manufacturing environments have been identified and explained. Key features of CAESAR V 2.0 which make it suitable for assisting rescuers have been stated and explained.

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6 BIOGRAPHY



Allan Chikwanha received his BSc in Mechanical Engineering at the University of KwaZulu-Natal. He is currently involved with research, design and development of an Urban Search and Rescue (USAR) robot at UKZN MR²G as a master's student.



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