International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 1, No. 3, October 2012

Research Paper

DESIGN AND DEVELOPMENTS OF INSPECTION ROBOTS IN NUCLEAR ENVIRONMENT: A REVIEW

G Shanmuga Sundar[1]*, R Sivaramakrishnan[1] and S Venugopal[2]

*Corresponding Author: **G Shanmuga Sundar,** ✉ gshanmugasundar@gmail.com*

In the current hi-tech world the application of robots has become the crucial role in industries. The exertions which were beyond the capacity of humans are now possible with robots. Particularly in the departments like inspections, Robots have become the essential substituent. In hazardous environments like nuclear waste management inspection robots associated with Non Destructive Testing (NDT) methods are really a necessitate one. In a view to meet such demands, this paper features the survey of available robotic inspection system which can accomplish the hazardous tasks. In nuclear industries the inspection works cannot be carried out by humans as there is a chance of nuclear exposure. To avoid such a miserable accident, the implement of robots in nuclear industries inspection is become mandatory. The main focus of this paper is to reveal the methodologies of design and development of different mechanisms and robot, their advantages and limitations.

Keywords: Inspection robot, Wall climbing robots, Ultrasonic probes, Articulated legs

INTRODUCTION

Humans are masters of world. Even though there are some jobs which are still beyond their scope. Humans created robots to make their hazardous tasks to get done. Generally robots are designed for a specific task. There are different types of robots based on their applications they are manufacturing, industrial, space exploration, transportation, medical, educational robots. The most essential demand of robots is in the manufacturing sector and nuclear power production sector where the humans are exposed to hazardous environment. To protect themselves from the harmful effects like radiation, high temperature, vibration, loud noises, etc., they employ the robots as their substitutes. In the current scenario there is a great demand for inspection robots. In inspection sector the most dangerous one considered is nuclear waste storage inspection.

[1] Department of Production Technology, MIT Campus, Anna University, Chennai, India.
[2] Remote Handling, Irradiation Experiments and Robotics Division, Indira Gandhi Centre for Atomic Research, Government of India.

Particularly in the departments like inspections in nuclear industries, the safety and the accuracy created the demand for new robots. In nuclear power stations many stainless steel canisters, are used to store vitrified intermediate level wastes. These tanks are prone to defects at the weldments. These welds need to be inspected throughout their service life for signs of damage. A newly designed articulated robot is expected to carry out the inspection tasks. That robot system must effectively serve as a substitute for a human worker, who would otherwise exposed to a dangerous and hazardous environments. Even though there are many researchers are going on, still there is no stable globally approved method for inspection to inspect the storage tanks of nuclear wastes. These demands pave the way for the new innovative robots.

The Problem Statement

Due to decline of non-renewable resources, the world has to rely on the nuclear technology for the power source. This scenario leads to construction of more nuclear power station stations, meanwhile the need for the inspection and maintenance of the stations also raise. There will a demand for more economical and flexible robot system, which can perform all the inspections activities of the nuclear power stations and make the nuclear power source to be a safer means of power generation. The objective is clear that there is a demand for the inspection robot in nuclear technology. The robot which can perform all the inspection activities like inspection of weld cracks, inspection of leakages, video graphing the hazardous area and the similar jobs is expected. It should be autonomous enough to control itself. The past and present robots technologies are analysed before designing the new robots. The survey of the available technologies is done, which is presented in this paper.

Motivation for the Review

The idea of doing the survey work as evolved from the similar works, which has been done in the past. These types of survey works give the reader the thought of available robots and the initiative to develop new, very economical robots. Terrence *et al.* (2003) have presented the survey of socially interactive robots. In this paper the design methods and components of the interactive robots are given. The impact of robots upon humans is also discussed in brief. This works concluded that robots can assist in health care, household staff, tour guides, and office assistant. The robots are also stepped in entertainment sector. Kolhalkar and Patil (2012) have presented a review of wall climbing robots. This paper gives a clear idea of robots involved in the dangerous conditions like cleaning glasses of sky-scrapers, maintenance of ship, aluminum aircraft inspection, etc. These types of literature surveys gave initiative to do a survey of robots depending upon applications.

Need for Review

To minimize human effort and amplify their comforts robots are required. Humans faced several difficulties to survive in this earth. Even now the struggle continues. To accomplish their most difficult task humans used robots. There are some who use robots for entertainment, some for education, and today robots can perform even most critical surgical operations. In spite of these works, the most

important utilization of robots is in the field of manufacturing and inspection. Whatever may be the jobs, the robots can surely capable of doing that works.

In this immense world there is new robots developed day-by-day. If we are need a robot for our specific demand, then this type of survey would be useful. One can match the available robot technology to their demand, instead of spending time on the same design again. For hazardous researchers like nuclear power generation, space exploration, construction, manufacturing etc, it is hard to conduct researchers just by then. To avoid wastage of time and capital the survey may be done to accomplish our goal. If the results are not matching the required demands then the new model can be designed and implemented. That is, the robots with maximum adaptability are needed. This paper would cater such demands.

SURVEY OF PRESENT ROBOTS

Robots involved in inspections are categorized according to their ability of motions. Some robots are straight line robots and some are flexible to move in all directions with high degrees of freedom. The survey is done to check for the availability for the robots that could meet our demand. To test out the availability of robots, we have to go through the past and current researches, which is fairly relevant to our needs. In this review different robot like climbing, magnetic, long reach articulated arms, pneumatically operated, automatic inspection and Tele-manipulator robots are studied.

Climbing Robots

Robots employed in the inspection purposes should be made adaptable to the situation. For the on job inspection researchers were done to design to make climbing robots Bing *et al.* (2007) have presented three climbing robots namely WIC, SADIE and Robug III. Out of which SADIE is a climbing robot as shown in Figure 1, with seven non-articulated legs developed for carrying out ultrasonic inspection and surface preparation inside reactor cooling gas ducts in power stations. The robot is designed to climb upside down from the top of the duct to inspect some of the welds. While its operation it is resisted by some ladder brackets. So SADIE is intended to carry a specially designed grinding package to eliminate the ladder brackets. There is a chance of mixing of these ladder brackets to get into the reactor, which causes huge devastation. To avoid this danger a special grab device is provided to remove them using a special grab mechanism to avoid endanger to the reactor. He has developed another robot named Robug III as a walking and climbing with eight articulated legs as shown in Figure 2,

Figure 1: SADIE Robot and Its Tool Packages

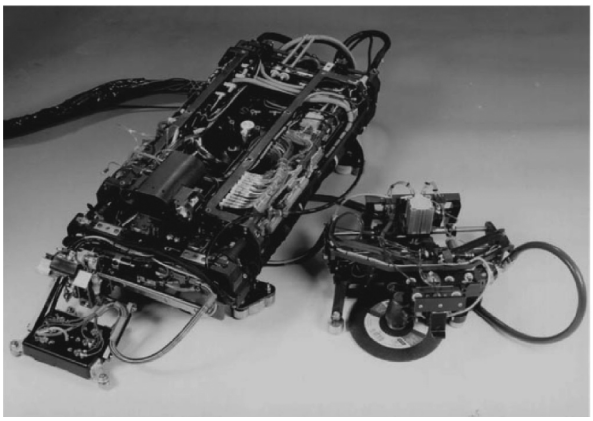


Figure 2: Robug III Robot

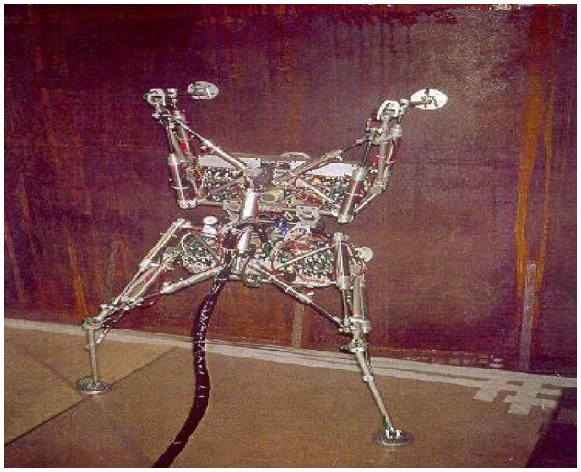
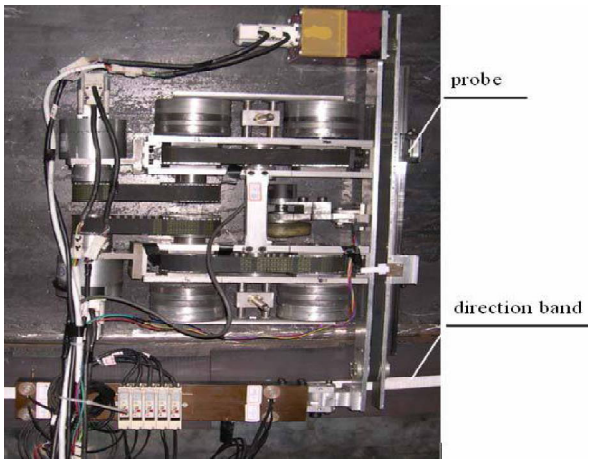


Figure 3: The Structure of the Modular Mobile Robot



developed for working in unstructured environment. In case of any accident, this robot may be useful in getting information about those places. It is fitted with a camera and a transmitter which helps us to gain access to those places. Its legs are controlled by a microprocessor which makes it more accessible. The robots with climbing tendency have a great scope in inspection. Habitually the researchers concentrated on climbing type of robots.

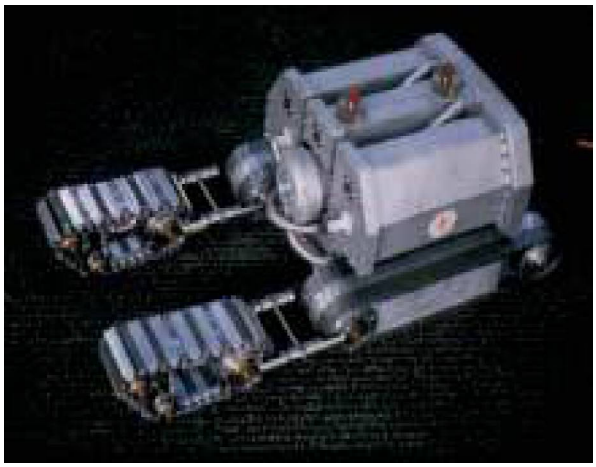
Magnetic Driven Robots

As the scope of climbing robots has become popular, then the innovations are done in making the flexible climbing robots. In this manner Fei and Song (2008) have developed a modular climbing-wall mobile robot with four magnetic wheels as shown in Figure 3, which can move on the vertical steel vessels and inspect the weld seam. It works on tandem scan mode. This system is made accurate by its components like manipulator module, ultrasonic probe and weld testing sensor. In this robot the manipulator module mainly consists of the robot body plate, magnetic wheels, DC servo motors. The ultrasonic probes module consists of motor, belt, belt gears, guide track, probes. The weld testing sensors module consists of four optical fiber sensors. The magnetic wheels are as designed, which consists of two pieces of magnet and three pieces of pure steel plates. This work proved the movement of the robot on the cylindrical vessel. The author concluded that the robot is applied practically for the reactor vessel inspection instead of old conventional machines in danger environment and it was found convenient, because of its modular structure.

Hua *et al.* (2008) have presented The robotic system which comprises of a magnetic robotics crawler wheels, the data storage system, the control system, the data storage system, the inspection system and the power console. In this work fuzzy CMAC is used to adopt the tracking control system for improving the performance capacity. Pichit *et al.* (2003) have designed an automated inspection process using the ultrasonic sensor for the storage tank wall. The iron storage tank wall,

normally subjected to the change of chemical level which can cause corrosion of the wall. This robot is capable to climb the tank wall vertically to detect the spots of corrosion. The author implemented five permanent magnetic wheels support the robot. They are capable to attach themselves on the walls. The microcontrollers used could give signals to the pc through interfaces. These robots face a limitation that they can be employed only in the ferrous structures. In Osaka Gas Co., Ltd., Konohanaku OSAKA, Japan (www.osakagas.co.jp) the inspection robot driven by magnetic wheels is used in inspection purposes. In this system the ultrasonic flaw detection probe is intended to carry out inspection works in the straight lines only. To change the spot of inspection the robot is to be moved manually. In the Field Robotics Centre at Carnegie Mellon University a mobile robot is implemented in inspecting the fuel storage tanks interiors. It is capable to inspect both above and under the ground. Hagen *et al.* (1994) presented the mobile robot named Neptune system to inspect the above ground storage tanks. It is designed to do unmanned entry and data collection in above ground storage tank. It consists of magnetically switchable robot crawler (as shown in Figure 4), on-board vision and ultrasonic sensors. The robot crawler is made up of anodized aluminum, which encloses all other necessary devices for inspection.

Figure 4: Neptune In-Tank Crawler Robot



Long Reach Articulated Arms

Laurent *et al.* (2010) presented an Articulated Inspection Arm (AIA) developed by European programme. It is made as a multi-purpose robot in remote handling of the vessel. It has the payload up to 10 kg. It is made with eight degrees of freedom and a wide span of eight meters. This inspection arm is used in the maintenance purposes too. The Idaho National Engineering and Environmental Laboratory (INEEL) has tanks which are used to store liquid nuclear wastes. The Robotic Tank Inspection End Effector (RTIEE) is an inspecting device mounted on the light duty utility arm. It is a visual inspection cum data collection device. It can be operated from the control trailers, which are usually outside the tank radiation area.

Pneumatic Controlled Inspection Systems

As the magnetic technology is limited to ferrous structures the pneumatic technology came to rise. The robots are designed with pneumatic grippers suitable to all surfaces. Senthil *et al.* (2004) designed pneumatic inspection robotic devices, which are a reliable non-destructive evaluation system of nuclear components. They presented that the inspection process can be carried out automatically using non-destructive methods. Their work led the way to many similar researches in developing the non-destructive

methods in inspection. The inspection process is carried out in the vertical surfaces with high accurate robotic devices. Tech Corr USA is an inspection service provider (Floyd, 2009). Floyd have presented the robot, which is used for both inspection and cleaning purposes. It is hydraulically driven, remotely operated robot designed to remove sludge from containments. It is provided with an on-board video system which provides operator visibility for the operator from the convenient safe locations. In addition to these Luk *et al.* (2005) has presented walking-climbing robots. The author added that instead reach manipulators suffer from low payload capacity and relatively large end point deflections. They introduced Nuclear Electric Robot Operator (NERO) robots as shown in the Figure 5. NERO is a pneumatically driven non-articulated legged vehicle. It used vacuum gripper feet to hold on the Reactor Pressure Vessel (RPV) surfaces. In these robots the pneumatic control valves were arranged so that in the event of electrical power failure, the system would fall safe by lowering the vehicle on to the surface. It is made to grip with all eight feet in the surface. The robot is provided with the television cameras, which allows the supervisor to oversee the operation from the distance safer from radiation. It is consoled with the PC for effective control over the hazardous surfaces.

Redrafted Robots from Existing Systems

In the nuclear power stations at Savannah River Site (SRS), Clyde *et al.* (2000) has developed new five robotics technology from the existing systems. The author redrafted system such as mobile robots, a pipe crawler, special manipulators, and custom-designed tooling. They added that SRS was one of the first sites to apply robotics in actual nuclear applications. Their motive is to reduce the radiation exposure to the working personnel. They have modified a bomb disposal robot and added a special cutting tool to remove the radioactive junction box with minimal radioactive exposure to personnel, as shown in the Figure 6. They modified a bomb disposal

Figure 5: NERO Robot and Its Control Console

Figure 6: The Remote Overhead Video Extendable Robot (ROVER)

robot by installing a new upper arm assembly and a tool-mounted camera. Finally they proved the mobile robot design as a working one for removing a junction box at the radio active environment.

In the nuclear station the direct viewing of the pits of radioactive waste exposes workers to radiation from the pits. As a result they developed the Remote Overhead Video Extendable Robot (ROVER) as shown in Figure 7, which provides multiple overhead video views from a considerable distance above the pits. Each camera and light can be remotely repositioned to effectively view the entire operation.

Figure 7: Mobile Teleoperator Used to Remove a Wall-Mounted Junction Box

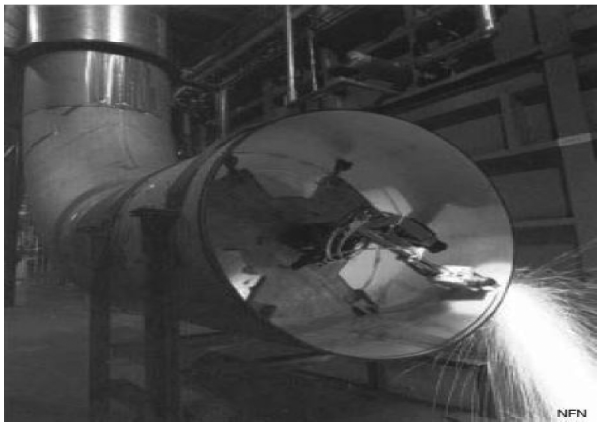
In a view to restart the SRS reactors an ultrasonic inspection of the reactor vessel was needed. The SRS-designed system as shown in Figure 8 includes the remote inspection robot, three camera positioners, a calibration mast, and a control center designed to be transported from reactor to reactor. A 5-ton crane was designed to be installed, operated, and removed on existing crane rails in the

Figure 8: Reactor Tank Inspection Robot

reactor building. Since all components entering the reactor vessel were long with relatively small diameters, strong backs were designed to transport the components and be placed to the vertical position without damage by a custom-designed erector. They finally concluded that the Reactor Tank Inspection System was successfully deployed in P, K, and L Reactors. It met all performance, cost, and schedule goals.

To remove the elbow section of a pipeline, which was in the underground concrete tunnel, he developed an internal pipe crawling system as shown in Figure 9, is used to transport the torch through the pipe because the elbow could not be removed externally. The pipe crawler moved in an inchworm motion using pneumatic cylinder. The resulting crawler was nearly 7 feet long and weighed nearly 125 pounds. Six miniature, low-light level, CCD cameras were installed on the crawler to help navigate and locate the elbow section. Clyde had proved that new robotic systems can be developed from the existing ones. As the demands for the inspection increases, the new technology has to be adopted. His innovation

Figure 9: The Elbow Cutting Pipe Crawler



in the robotic technology in nuclear industry has paved the way for the upcoming researches.

Auto Inspection Robots

Due to automation of world the need of the automatic robots has created. Fu *et al.* (2005) have introduced their new auto-inspection robot system for weld inspection in nuclear pipes. Their robot system consists of half clamp as mounting unit and a half base as circumferential rotational joints, an arm, a controller and an Industrial Personal Computer (IPC) unit. They made his system reconstruct able by adjusting the size of the arm to adapt to the different working conditions. The arm consists of the CCD camera is used for scanning and monitoring the procedures. The clamp is for mounting purpose. The system can also perform trajectory planning, 3D simulation, auto-operation, ultrasonic signal analysis and 3D reconstruction according to the measured flow data. The author finish off by saying that there is an urgent demand for this type of low cost inspection system.

Tele Manipulator Robots

Researchers continued for creating more feasible and easy operating robots. The concept of Tele manipulator is so introduced. Telemanipulator are capable of inspecting using the cameras. It consists of two similar systems connected either by mechanical or electrical means. Jayarajan *et al.* (1998) have developed the Telemanipulator in which a master slave arrangement is provided. The master is assembled in a non-hazardous area. The slave is made to work in the unstructured environment. The slave would exactly reproduce the motions performed by the master in the remote locations. There is only electrical contact between the master and the slave robot. This technology is milestone in the inspection robots, as it provides cent percent safety to operator. The slave is provided with a vision camera which allows the accurate motions in the unsafe area. These manipulators are provided with a actuators, sensors and force transmission mechanisms. This manipulator system is being successfully installed in Bhabha Atomic Research Centre (BARC) for Waste management Project Division. Its performed is evaluated for the intended tasks.

CONCLUSION

This paper has given an overview of the currently available inspection robots. The features and of the present robots are dealt briefly. The classification of the robots based on their mobility has being presented briefly. The climbing robots required the special arrangement to enable its movement like clamping devices, holders etc. which has limited its usage. The magnetically driven robots are suitable only in the ferrous background conditions. The pneumatically driven robot has great advantages in those conditions where the magnetically driven robot fails.

The redrafted robots are very economical as their base is previously available. They are developed for specified purposes and they have less lifetime. These robots are not reliable in many conditions. The auto inspection and Telemanipulator are made up modern technology and can meet any situations. These robots are safer compared to other system of robots. Finally it is preferable to develop these types of robots. As the researches continue in the world there will be increased demand for robots in future. To conclude the new robot system developed now are going to have a great demand in the near future.

ACKNOWLEDGMENT

G Shanmuga Sundar is very thankful to his research supervisor, Dr R Sivaramakrishnan, Associate Professor, Department of Production Technology, MIT, Chennai for his constant guidance and motivation throughout this research work. This work is also supported by Dr S Venugopal, Head/Remote Handling, Irradiation Experiments and Robotics Division, Indira Gandhi Centre for Atomic Research, Government of India.

REFERENCES

1. Bing L Luk, Louis K P Liu and Arthur A Collie (2007), "Climbing Service Robots for Improving Safety in Building Maintenance Industry", *Bioinspiration and Robotics Walking and Climbing Robots*, ISBN: 978-3-902613-15-8, available at www.itechonline.com
2. Clyde R Ward, Ivan Lewis W, Robert F Fogle, Paul S Hebert, Phillip J French and Frank M Heckendorn (2000), "Robotics Applications at the Savannah River Site", WSRC-MS-2000-00061.
3. Fei Yanqiong and Song Libo (2008), "Design and Analysis of Modular Mobile Robot with Magnetic Wheels", *WSEAS Transactions on Applied and Theoretical Mechanics*, Vol. 3, No. 12.
4. Floyd A Baker (2009), TechCorr USA, available at www.techcorr.com
5. Fu X G, Yan G Z, Yan B and Liu H (2005), "A New Robot System for Auto-Inspection of Intersected Welds of Pipes Used in Nuclear Power Stations", *The International Journal of Advanced Manufacturing Technology*, Vol. 28, Nos. 5-6, pp. 596-601.
6. Hagen Schempf, Brian Chemel and Nathan Everett (1994), "Neptune:Above-Ground Storage Tank Inspection Robot System", *IEEE Robotics & Automation, Society Magazine*, June.
7. Hua Wang Xiaodiao, Huang Rongjin Hong and Chenggang Fang (2008), "A New Inspection Robot System for Storage Tank", Nanjing University of Technology.
8. Jayarajan K, Dutta A, Kar D C, Sahu R, Zende D G, Bhaumik T K, Venkatesh D and Ramakumar M S (1998), "Design of a Telemanipulator for Radioactive Waste Management", Division of Remote Handling and Robotics, BARC, Mumbai, India.
9. Kolhalkar N R and Patil S M (2012), "Wall Climbing Robots: A Review", *International Journal of Engineering and Innovative Technology (IJEIT)*, Vol. 1, No. 5, May.

10. Laurent Gargiulo, Houry M, Kammerer N, Keller D, Measson Y, Piolain G and Verney A (2010), "Long Reach Articulated Robots for Inspection in Hazardous Environments, Recent Developments on Robotics and Embedded Diagnostics", *Applied Robotics for the Power Industry (CARPI)*, 1st International Conference on Date of Conference October 5-7.

11. Luk B L, Collie A A, Cooke D S and Chen S (2005), "Walking and Climbing Service Robots for Safety Inspection of Nuclear Reactor Pressure Vessels", *Asia Pacific Conference on Risk Management and Safety*, December 01-02, pp. 432-438, Hong Kong, China.

12. Pichit Rerkshanandana, Thavida Maneewarn, Rangsan Boonnara, Eakkalak Krueyot and Prasittiporn Pongwasin (2003), "Ultrasonic Tank Inspection Robot", Institute of Field Robotics.

13. Robotic Tank Inspection End Effector, a Summary Report in Innovative Technology, Department of Energy US.

14. Senthilkumaran G, Kasiviswanathan K V, Baldev Raj, Nagarajan T and Singaperumal M (2004), "Pneumatic Inspection Robotic Devices for Reliable Nondestructive Evaluation of Nuclear Components", *International Symposium of Research Students on Materials Science and Engineering*, Indian Institute of Technology Madras.

15. Terrence Fong, Illah Nourbakhsh and Kerstin Dautenhahn (2003), "A Survey of Socially Interactive Robots", *Robotics and Autonomous Systems*, pp. 143-166.

16. www.frc.ri.cmu.edu /~Hagen/samplers/text/NEPTUNE_Sampler.html

17. www.osakagas.co.jp