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Robot Applications in Hazardous Environments: A Review

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ABSTRACT: *Robots are developed basically to minimize the human effort and increase the quality of work. They find their application in a variety of fields, one such being the radioactive environment, generally present in the nuclear power plants. Safety of humans is of prime concern in the radioactive environments. Humans are prone to detrimental health effects like cancer. Cancer is considered as the primary health effect caused mainly due to radiation. Radiation can lead to changes in DNA, called as mutations. Sometimes the body fails to repair these mutations or even creates mutations during repair. The mutations can be teratogenic or genetic. Genetic mutations are often passed on to offspring. These are some of the health problems that are being faced by humans in radioactive environments. There are different types of robots that are being used in the nuclear power plants which reduce the human exposure to the harmful and dangerous radiations like alpha, beta and gamma. Even though these robots are highly expensive, they reduce the strain of humans and are also cheaper than the skilled workers in long run. In this paper, an attempt is made to review the importance of robots in radioactive environments. This paper thoroughly discusses the issue by studying the major radiation disasters taken place. Also an emphasis is given on understanding the basic design and methodology of these robots. The future of these robots is expected to reach a phase where the nuclear power plants have very less human intervention.*

Keywords: *Robots, Radioactive environment, Radiation*

I. INTRODUCTION

A radioactive environment is full of high energy emissions like α, β and γ radiations. These radiations are emitted by radioactive materials. Professional workers working in such environments face serious health hazards. As such, these radiations are very harmful to human beings, even leading to deaths. As per the international regulations, there is a limitation regarding the time professional workers can spend in such environments. There have been many cases of accidents in radioactive environments. Chernobyl, Lucens and Fukushima disaster are the major ones to name a few. Application of robots in critical places like nuclear power plant, where the work is quite difficult, is really worthful. Robots are used to prevent exposure of humans to radiations in nuclear power plants. Hence, it is essential to use robots in such an environment. In this paper, an attempt is made to understand the robot terminology.

II. ROBOTS

Czech writer, Karel Capek [1], defines robot as a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks. Trevor Hunter defines robot as a machine that resembles a human and does mechanical actions on command is called a robot.

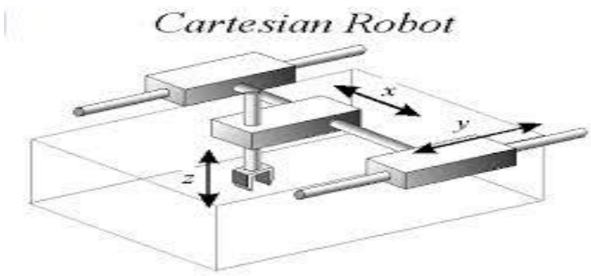
2.1 Components of Robots:

A robot essentially consists of the following components: arm, end effectors, controller, drive, actuator and sensors.

Arm: Nanjundeswar [6] explains about the arm of a robot as an important part in the robotic Architecture. It positions the end effectors and the sensors that the robot will require. Most arms resemble the human hands having fingers, wrists, and elbows.

End Effectors: End effectors are the hand connected to the arm. However, in robots, the end effectors can be of various shapes and sizes. [6]

Controller: The controller functions as the "brain" of the robot. It can also network to other systems so that the robot may work together with other robots or machines.
Drive: The drive is the engine of the robot. It enables mobility and movements between the joints of the arm. It can be powered by air, electricity, and/or water.
Actuators: They are generally muscles of robot. These can be electric motors, hydraulic systems, pneumatic systems, or any other system that can apply forces to the system.
Sensors: Yinong Chen [5] describes sensor as a converter that measures a physical quantity and converts it into a signal which can be read by an observer. Sensors are classified as vision sensors, tactile and proximity sensors touch sensors and voice sensors.
Vision sensors: Robot vision is made possible by means of video camera a sufficient light source and a computer programmed to process image data. The camera is mounted either on the robot or in a fixed position above the robot so that its field of vision includes the robots work volume.
Tactile and proximity sensors: Yinong Chen [5] explains that tactile sensors provide robot the capability to respond to contact forces with other objects within the work volume present. Tactile sensors can be divided into two types:
Touch sensors: Touch sensors are used to indicate whether contact has been made with object. Example is a micro switch.
Stress sensors: Stress sensors are used to measure the magnitude of the contact force.
Voice sensors: Voice sensors are used to control the activities of a robot through voice programming.
2.2 Configurations of Robots:
Robots are capable of various arm manipulations due to various configurations.
Cartesian configuration: A robot with Cartesian configuration consists of three slides. The three slides are parallel to the x, y, and z axes of the coordinate system.



Cylindrical configuration: In this configuration, the robot body is a vertical column. The arm consists of several slides which allow the arm to be moved up or down and in and out with respect to the body.

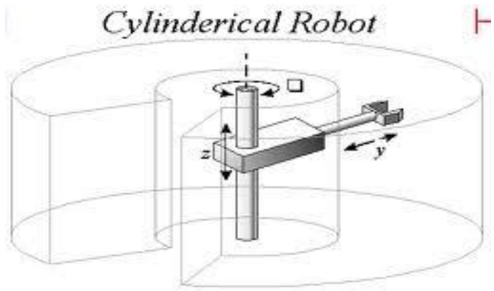


Fig 2: Cylindrical configuration [5]

Polar configuration: The workspace of a polar configuration robot is a partial sphere.

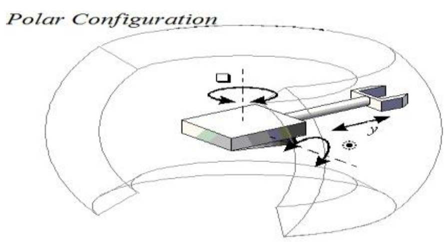


Fig 3: Polar configuration [5]

Jointed-arm configuration: This is a combination of cylindrical and articulated configurations having similar appearance to the human arm. It consists of a human shoulder, elbow, and wrist.

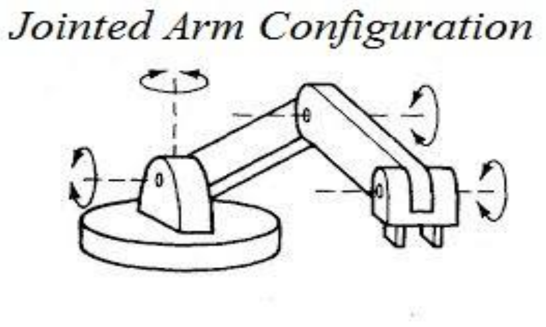


Fig. 4: Cylindrical configuration [5]

2.3 Drives in Robots:

There are three basic drive system used in commercially available robots: [1]

1. Hydraulic drive: These are designed to actuate linear or rotational joints. The main disadvantage of a hydraulic system is that it occupies more space in surplus to that space required by the robot.
2. Electric drive: It provides less speed and strength as compared with a hydraulic system,. These are used for smaller robots. Electric drive systems are more accurate, exhibit better repeatability, and are cleaner to use.
3. Pneumatic drive: It is used for smaller robots. These robots have few degrees of freedom; carry out simple pick-and-place material handling operations.

2.4. Advantages of Robots:

Following are the advantages of robots.

1. Increase productivity, safety, efficiency, quality, and consistency of products.
2. Can work in hazardous environments.
3. Need no environmental comfort.
4. Can work continuously without any human needs and illnesses.
5. Have repeatable precision at all times.
6. Are more accurate than humans; they may have milli or micro inch accuracy.
7. Can have capabilities beyond that of humans.
8. Can process multiple stimuli or tasks simultaneously, humans can only one.
9. Replace human workers who can create economic problems.

2.5. Applications of robot:

Robots find their applications in variety of tasks namely material handling, processing and inspection operations.

Material-handling applications:

It involves the movement of material or parts from one location to another. Examples are part placement, palletizing and/or de-palletizing, machine loading and unloading.

Part Placement: It is the relatively simple pick-and-place operation. It needs a low-technology robot of the cylindrical coordinate type.

Palletizing and/or De-palletizing: The parts are stacked or unstacked. For example, process of taking parts from the assembly line and stacking them on a pallet or vice versa.

Machine loading and or unloading: Robot transfers parts into and or from a production machine.

Processing Operations:

In these applications, robot performs a processing procedure on the part. It is equipped with some type of process tooling at its end effector. Industrial robot applications in the processing operations include spot welding, arc welding, riveting, spray painting, machining, metal cutting, deburring, polishing etc.

Inspection operation:

Inspection work requires high precision and patience, and human judgment is often needed to determine whether a product is within quality specifications or not.

III. RADIATION & RADIOACTIVITY

Radiation is the emission and propagation of energy in the form of alpha, beta and gamma rays or particles. The radiation, including alpha particles, nucleons, electrons, and gamma rays, is emitted by a radioactive substance like uranium, radium, polonium, protactinium, thorium, radon, plutonium, neptunium, hafnium and curium. [11]

3.1. Hazards of radioactivity:

Dr. Wigg [8] classifies and explains the hazards of radioactivity as under:

Somatic effects:

Somatic effects are a result of personal exposure to ionizing radiation and are a direct manifestation of cell death, blocked or delayed cell division or mutation of genetic material.

Hereditary effects:

Hereditary effects appear in the first and later generation progeny of the exposed individual, and are caused by alteration of the genetic material of the exposed individual.

3.2. Effects of Radiation in Radioactive Environments:

Cellular Sensitivity: Radiation in most of the cases affects the body cells. If this damage is severe enough, the affected cell dies. In some instances, the cell is damaged but is still able to reproduce. The daughter cells, however, may be lacking in some critical life-sustaining component, and they die. The other possible effect of radiation exposure is that the cell is affected in such a way that it does not die but is simply mutated. The mutated cell reproduces and thus perpetuates the mutation. This could be the beginning of a malignant tumour. [17]

Organ Sensitivity: The sensitivity of the various organs of the human body correlate with the relative sensitivity of the cells from which they are composed. For example, since the blood forming cells were one of the most sensitive cells due to their rapid regeneration rate, the blood forming organs are one of the most sensitive organs to radiation. Muscle and nerve cells were relatively insensitive to radiation, and therefore, so are the muscles and the brain. [17]

Genetic Effects: The Genetic effect involves the mutation of very specific cells i.e., sperm or egg cells. These reproductive cells are passed to the offspring of the individual exposed. Radiation is an example of a physical mutagenic agent. There are many chemical agents as well as biological agents (such as viruses) that cause mutations. Radiation increases the spontaneous mutation rate, but does not produce any new mutations. No such transformations have been observed in humans. Genetic effects from low dose exposures have not been observed in human studies. It is speculated that, during the early stages of fertilization, reproductive cells may produce significant changes in the fertilized egg that the result is a nonviable organism which gets aborted. Radiation induced cancer is well documented. Many studies have been completed which directly link the induction of cancer and exposure to radiation. For example:

Lung cancer - uranium miners

Bone cancer - radium dial painters

Thyroid cancer - therapy patients

Breast cancer - therapy patients

Skin cancer – radiologists

Leukaemia - bomb survivors, in-utero exposures, radiologists, therapy patients. [17]

IV. MAJOR ACCIDENTS DUE TO RADIATION

Lucens Reactor, Switzerland (1969):

The accident was caused by water condensation forming on some of the magnesium alloy fuel element components during shutdown and corroding them. The corrosion products from this accumulated in some of the fuel channels. One of the 73 vertical fuel channels was sufficiently blocked by it to impede the flow of carbon dioxide coolant so that the magnesium alloy cladding melted and further blocked the channel. The increase in temperature and exposure of the uranium metal fuel to the coolant eventually caused the fuel to catch fire in the carbon dioxide coolant atmosphere. The pressure tube surrounding the fuel channel split because of overheating and bowing of the burning fuel assembly, and the carbon dioxide coolant leaked out of the reactor [12].

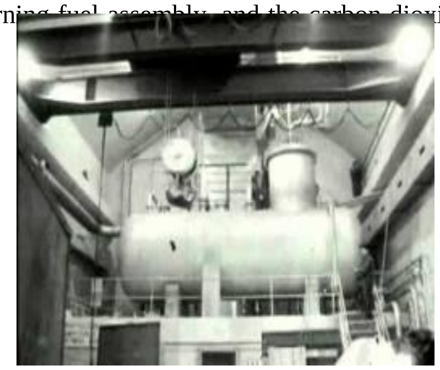


Fig. 5: Lucens Reactor Diagram

Three Mile Island Accident, Pennsylvania, USA (1979):
The reactor involved in the accident, Unit 2, was a pressurized water reactor manufactured by Babcock & Wilcox. The accident began with failures in the non-nuclear secondary system, followed by a stuck open pilot-operated relief valve (PORV) in the primary system, which allowed large amounts of nuclear reactor coolant to escape. The mechanical failures were compounded by the initial failure of plant operators to recognize the situation as a loss-of-coolant accident due to inadequate training and human factors, such as human-computer interaction design oversights relating to ambiguous control room indicators in the power plant's user interface. In particular, a hidden indicator light led to an operator manually overriding the automatic emergency cooling system of the reactor because the operator mistakenly believed that there was too much coolant water present in the reactor and causing the steam pressure release [10].
Chernobyl Disaster, Chernobyl Nuclear Power Plant, Ukraine, USSR (1986):
An accident occurred at Unit 4 of the nuclear power station at Chernobyl, Ukraine. It was caused by a sudden surge of power. It destroyed the reactor and released massive amounts of radioactive material into the environment. Boron and sand were poured on the reactor from the air to stop the fire and prevent the accident. In addition, the damaged unit was entombed in a temporary concrete "sarcophagus," to limit further release of radioactive material. Control measures to reduce radioactive contamination near the plant site include cutting down and burying a pine forest of approximately 1 square mile. The three other units of the four-unit Chernobyl nuclear power station were subsequently restarted. The Soviet nuclear power authorities presented an initial report on the accident at an International Atomic Energy Agency (IAEA) meeting in Vienna, Austria, in August 1986. Pripyat, the town near Chernobyl where most of the workers at the plant lived before the 1986 accident, was evacuated several days after the accident, because of radiological contamination. It was included in the 30-km Exclusion Zone around the plant and is closed to all but those with authorized access. The Chernobyl accident caused many severe radiation effects almost immediately. 2 workers died within hours of the reactor explosion and 134 received high radiation doses and suffered from acute radiation sickness. Of these, twenty eight workers died in the first four months after the accident. [13]
Fukushima Daiichi Nuclear Disaster, Japan (2011):
Fukushima prefecture in Northern Japan, consist of six nuclear units at the Fukushima Daiichi station and four nuclear units at the Fukushima Daini station. All the units at the Fukushima complex are boiling water reactors, with reactors 1 to 5 at the Fukushima Daiichi site being the General Electric Mark I design, which is also used in the United States. The huge earthquake and tsunami that struck Japan's Fukushima Daiichi nuclear power station knocked out backup power systems that were needed to cool the reactors at the plant, causing three of them to undergo fuel melting, hydrogen explosions, and radioactive releases. Radioactive contamination from the Fukushima plant forced the evacuation of communities up to 25 miles away and affected up to 100,000 residents, although it did not cause any immediate deaths. [14]

V. ROBOTS IN RADIOACTIVE ENVIRONMENTS

Today robots are widely used in the nuclear industry to perform automated and repetitive work or to execute hazardous tasks that are dangerous to human beings. First, profitability is the motivation to switch from a regular worker to an automated system. Second, safety of the worker and regulation are issues that should not be ignored. In nuclear science, protection of workers became a catalyst for the development of robotics.

HAZBOT operating in atmospheres containing combustible gases:
The Mobile All-Terrain Laboratory Platform (MALP) is a remote-controlled, wheeled, robotic probe, used to explore alien planets without endangering personnel. MALPs contain equipment used to determine such information as the breathability of the atmosphere and the presence of a working DHD on a planet to be explored. Sensors include a high-resolution tilt able colour video camera, laser range finder, spectrometer, a small directional microphone, a Geiger counter, sensors for detecting air pressure/temperature, atmospheric composition and even if the MALP is on its side. MALPs were first seen in the Star gate feature film. JPL loaned the production its Hazbot III for this purpose. [15]

Fig. 6: HAZBOT Robot [15]

VI. CONCLUSION

It is understood through the disasters of Lucens, Three Mile Island, Chernobyl, and Fukushima that radioactive environments are unsuitable to work for humans as they are prone to radiation and at the same time are vulnerable to many diseases. Accordingly there is a limitation for humans to work in radioactive environments i.e. in terms of time. Hence replacing a human with robots is beneficial as robots not only work with good efficiency and performance as compared to humans but also reduce the risk of health hazards.

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