Review on Robotics Safety

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***Abstract*: Typical hazards are impact and trapping by the mechanisms, and movement of robot arm or dropping work pieces. Malfunction and human error may also lead to unexpected movement of the robot arm, which can crush and cause injury to persons around. Other hazards are electrical shock, burns, radiation, fume, etc. The robot work envelope can be guarded by fixed barriers with interlocked gates for access and incorporating parts transfer by shuttle mechanism or rotary positioned. Trip and presence sensing devices can also be used to guard the work envelope of robot by means of photoelectric light beams or pressure sensitive mats which both must be a fail to safety type. At close proximity to robot, trip devices may be fitted on the robot arm itself for stopping the robot movement when tripped.**

***Keywords*: General-Purpose Autonomous Robots, Technological trends, various safety devices**

1. INTRODUCTION

- 1.1 An industrial robot can be defined as a position controlled, reprogrammable, multifunctional manipulator having a number of degrees of freedom in three-dimensional space and capable of handling materials, parts, tools, or specialised devices through variable programmed motions for the performance of a variety of tasks. Due to the characteristics of the industrial robot, it can present two opposing viewpoints in terms of industrial safety. The application of industrial robots permits the removal of the need for humans to perform certain dangerous and harmful operations, hence increasing safety. Applications in areas like welding, forging, sandblasting, painting, etc., enable workers to be free from adverse and unsafe working conditions. However, on the other hand, the industrial robots themselves can also create dangerous conditions and threaten human safety. Accidents and even fatalities as reported from overseas have proven that industrial robots can be hazardous if no safeguard is provided to eliminate the potential hazards. Therefore, it is essential that robot users and manufacturers recognize the potential hazards and implement safeguards to eliminate the hazards. This booklet describes hazards associated with the application of industrial robots and the basic principles of guarding to ensure human safety. Hazard analysis and the safety precautions and procedures to be taken for programming and maintenance of the robot are also discussed.

1.2 OBJECTIVES OF THE STUDY:

- Acquaintance with robotic safety.
- Understanding safety standards.
- Recognize safety reliability requirements.
- Familiarity with human factor issues in robotic environment.
- Awareness of safety sensors and monitoring.
- Realize safeguarding.
- Perceiving the important factors of training.
- Apprehending safety guidelines.

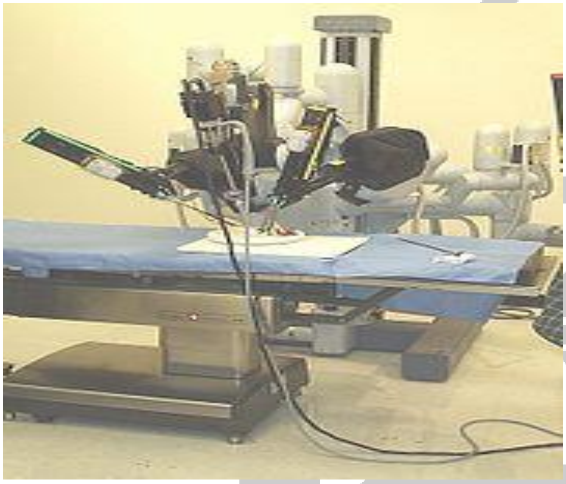
1.3 BASICS TO ROBOTS

A robot is a virtual or mechanical artificial agent. In practice, it is usually an electro-mechanical machine which is guided by computer or electronic programming, and is thus able to do tasks on its own. Another common characteristic is that by its appearance or movements, a robot often conveys a sense that it has intent or agency of its own.

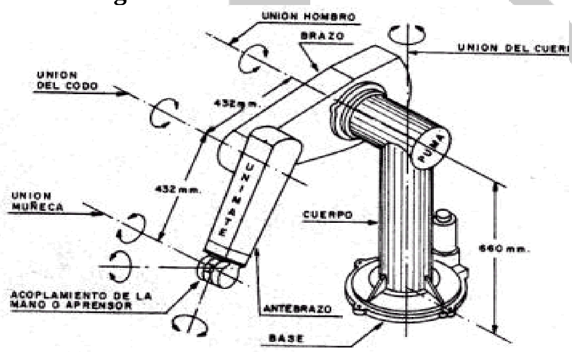
2. DEFINATION:

The word robot can refer to both physical robots and virtual software agents, but the latter are usually referred to as bots. There is no consensus on which machines qualify as robots, but there is general agreement among experts and the public that robots tend to do some or all of the following: move around, operate a mechanical limb, sense and manipulate their environment, and exhibit intelligent behavior, especially behavior which mimics humans or other animals.
There is conflict about whether the term can be applied to remotely operated devices, as the most common usage implies, or solely to devices which are controlled by their software without human intervention. In South Africa, robot is an informal and commonly used term for a set of traffic lights.
Stories of artificial helpers and companions and attempts to create them have a long history but fully autonomous machines only appeared in the 20th century. The first digitally operated and programmable robot, the Unmated, was installed in 1961 to lift hot pieces of metal from a die casting machine and stack them. Today, commercial and industrial robots are in widespread use performing jobs more cheaply or with greater accuracy and reliability than humans. They are also employed for jobs which are too dirty, dangerous or dull to be suitable for humans. Robots are widely used in manufacturing, assembly and packing, transport, earth

and space exploration, surgery, weaponry, laboratory research, and mass production of consumer and industrial goods.
It is difficult to compare numbers of robots in different countries, since there are different definitions of what a "robot" is. The International Organization for Standardization gives a definition of robot in ISO 8373: "an automatically controlled, reprogrammable, multipurpose, manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications." This definition is used by the International Federation of Robotics, the European Robotics Research Network (EURON), and many national standards committees.
The Robotics Institute of America (RIA) uses a broader definition: a robot is a "re-programmable multi-functional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks." The RIA subdivides robots into four classes: devices that manipulate objects with manual control, automated devices that manipulate objects with predetermined cycles, programmable and servo-controlled robots with continuous point-to-point trajectories, and robots of this last type which also acquire information from the environment and move intelligently in response.
There is no one definition of robot which satisfies everyone, and many people have their own. For example, Joseph Eagleburger, a pioneer in industrial robotics, once remarked: "I can't define a robot, but I know one when I see one."According to Encyclopedia Britannica, a robot is "any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner". Merriam-Webster describes a robot as a "machine that looks like a human being and performs various complex acts (as walking or talking) of a human being", or a "device that automatically performs complicated often repetitive tasks", or a "mechanism guided by automatic controls".
Modern robots are usually used in tightly controlled environments such as on assembly lines because they have difficulty responding to unexpected interference. Because of this, most humans rarely encounter robots. However, domestic robots for cleaning and maintenance are increasingly common in and around homes in developed countries, particularly in Japan. Robots can also be found in the military.



2.1 Defining characteristics:



- Literature Review
- 2.1 Safety for Human–Robot Interaction (Danica (Dana) Kulić, 2005)
- This thesis develops human–robot interaction strategies that ensure the safety of the human participant through planning and control. The control and planning strategies are based on explicit measures of danger during interaction. The level of danger is estimated based on factors influencing the impact force during a human-robot collision, such as the effective robot inertia, the relative velocity and the distance between the robot and the human.
- A danger criterion is developed for use during path planning based on static and quasi-static danger factors, such as the relative distance and the overall robot inertia. A planner algorithm is proposed that minimizes this criterion. A danger index, developed for the real-time safe control module, tracks dynamic danger parameters such as the relative velocity and the effective inertia at the impact point. The safe control module uses this index to identify and respond to real-time hazards not anticipated in

the planning stage. Both the planning and the real-time safe control strategy have been tested in simulation and experiments.

➢ Another key requirement for improving safety is the ability of the robot to perceive its environment, and specifically the human behavior and reaction to robot movements. This thesis also examines the feasibility of using human monitoring information (such as head rotation and physiological monitoring) to further improve the safety of the human robot interaction. A human monitoring module is developed using machine vision and physiological signal monitoring. The vision component tracks the location of the human in the robot's workspace, as well as the human head orientation. The physiological signal component monitors the human physiological signals such as heart rate, perspiration rate, and muscle contraction, and estimates the human emotional response based on these signals. If anxiety or stress is detected, the robot takes corrective action to respond to the human's distress. The planning, control and human monitoring components are integrated in a robotic system and tested with human subjects. A systematic and safe interaction strategy utilizing the methods described above, and applicable to a range of human-robot interaction tasks, is presented.

2.2 Assessing Safety Culture, Values, Practices, and Outcomes (Everon C. Chenhall, 2010)

➢ The purpose of this study was to identify where safety performance improvements can be made, thus establishing a foundation for further study by the company to formulate specific recommendations within the identified areas. The data were analyzed to determine whether five organizational practices and values described herein were predictors of 2009 safety performance. Accordingly, this non-experimental comparative study examined differences in safety culture dimensions between plants that achieved and failed to achieve their 2009 safety goals. The Competing Values Framework (Quinn & Kimberly, 1984) was adapted to assess safety culture strengths and congruencies among plants as an extension of the work of Silva, Lima, and Baptista (Isla Díaz & Díaz Cabrera, 1997, p. 643; 2004, p. 643) and Díaz-Cabrera (2007). Additionally, the underlying values, leadership types, and culture orientations measured through the Questionnaire of Safety Culture Values and Practices were tested for the first time as predictors of accident data. Despite considerable research on safety climate and culture predictors of accidents in organizations (Clarke, 2006), "the practical significance of these factors in the prevention of accidents remains undetermined" (Isla Díaz & Díaz Cabrera, 1997, p.643).

➢ The researcher analyzed the combination of the difference and associational research

➢ Questions. Exploration of the first research question involved analyzing the differences

➢ Among the plants based on the results of the One-Way ANOVA for the five safeties culture values and practices scores. Research question two was subdivided into three questions to clarify the three safety performance indicators (OSHA, LTA, and severity). The results of the independent t-tests compared the safety culture values and practices scores across the plants that achieved and failed to achieve 2009 safety goals for Occupational Safety Health Administration (OSHA) incident rates, Lost Time Away (LTA), and severity rates.

➢ Neither safety culture type scores nor safety culture values and practices scores were predictors of 2009 OSHA, LTA, or severity rates. The t-test results indicated large effects on a) company values, b) communication, c) and usage of accident information between the four plants that did and did not achieve 2009 LTA and severity goals, despite non-significant results. Differences among the plants were noted and analyzed for trends.

2.3 Safety Analysis and Integration for Robotic Systems - Application To A

➢ Medical Robot for Tele-Echography

Now a day, as many new application areas for robotic systems emerge, safety is becoming critical Indeed, service robots, including medical robots, share their working area or have a close interaction with humans. Safety, which already was an important concern for industrial robot is now the major preoccupation. The term "robot safety" may be interpreted as the preven article presents a deductive method for the safety analysis and integration of a robotic system.

➢ This method uses well-known analysis techniques for computer control systems but include the use of a formal language (Unified Modeling Language) to combine safety analysis with the development process. Human factors are presented in the first section, where the contribution of this field to safety is developed. A second section discusses about the assessment of hazard sand risks of the whole system. The third section presents the use of assessment methods such as Failure Modes and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) which identify potential unit errors resulting in hazards. The fourth section is about the choices of corrective measures guided by the previous steps. Finally the paper concludes with a discussion about how the steps of this safety analysis follow from each other. Each step of the analysis will be presented with a case study of a system for robotic tele-echography. TER is atele-robotic system designed and developed by a French consortium composed of universities, hospitals and industrial companies. The slave robot is tele-operated by an expert clinician who remotely performs the ultrasound scan examination. A virtual probe is mounted on the master interface device. The real probe is placed on the slave robot end-effector.

2.4 Implementation of Functional Safety in a Robotic Manufacturing Cell

➢ Darshana M. Kamtekar inNovember 2009The past 50 years have seen a staggering amount of change in the technology and the business of process automation. The programmable logic controller (PLC) based control and monitoring system is a proven technology used to not only control processes but also to perform safety functions for processes in many industrial applications. There are many opportunities for improvements in any process or manufacturing system. One of the opportunities is achieving accurate safety function for measurement and process control to prevent human injury or death. The programmable electronic systems (PES) such as PLC systems are increasingly being used to perform safety functions as an integral part of the process or plant control system. A Robotic Manufacturing Cell is an example of a PES system and is used as an experimental setup for this work. The IEC 61508 standard defines various phases involved in the overall safety lifecycle for the PES system. This thesis study

➢ Concentrates on such phases that include safety analysis methods, selection of an appropriate safety control system, implementation of safety as per the standard and safety validation. In this study four test cases are selected to perform safety analysis and implementation. It is verified how the conventional safety analysis method (FMEA) can be used to estimate the risk associated with each test case. As recommended by IEC 61508, a Risk-Graph method is used to calculate the Safety Integrity Level (SIL) requirement for each test case. A number of factors are required to be considered for selecting the appropriate safety control system architecture. After studying these factors and the safety analysis results, the Siemens safety

➢ PLC-based control system with SIL 3 configuration is selected for this application. IEC

➢ 61508 also recommend implementation of independent control systems for normal operation and safety. This study demonstrates how two independent PLC based control systems, one for normal operations and other for safety-related functions, are implemented to offer the most effective solution for this application. This is achieved by using PLCs from two different manufacturers, a non-safety PLC for normal operations and a Siemens safety PLC for safety-related functions. This study focuses on Machine Safety, and it can be used as a guideline for implementation of functional safety in real-life manufacturing environment.

3. METHODOLOGY OF ROBOTIC SAFETY

3.1 HAZARDS ASSOCIATED WITH ROBOTS

➢ The main hazard associated with the application of industrial robot is the working envelope of the robot. The ability of the robot to move in free space which covers a wide area, change configuration and produce unexpected motion immediately can cause hazards to persons operating or standing in the vicinity of the robot. Therefore in any robot installation, hazard analysis should be carried out to identify hazards so that safeguards can be implemented to prevent the occurrence of accidents. Malfunction and human error can lead to the unexpected movement of the industrial robot which include:

(a) (Aberrant behavior of robots caused by control system faults.

(b) Jamming of servo-valves.

©. (Robot movement cutting its umbilical cord.

(d) Splitting of unions on exposed hydraulic hoses.

(e)Fault in data transmission causing a larger than anticipated movement of the robot arm.

(f) Faults of welding gun and tooling parts.

(g) Programming and other operational errors.

(h) Precision deficiency, deterioration.

(i) Incompatibility of jigs and other tools.

➢ There are basically three potential hazards associated with robotic systems which are as follows:

➢ Impact — this involves such things as being struck by a moving part of the robot, or by parts or tool carried or manipulated by the robot. It can be caused by the unexpected movement of the robot or by the robot ejecting or dropping work pieces or molten metal.

➢ Trapping — this can be caused by the movement of the robot in close proximity to fixed objects like machines, equipment, fences, etc. Trapping points can also be caused by the movement of the work carriages, pallets, shuttles or other transfer mechanisms. They can also be presented on the robot itself on the arm or mechanism of the robot.

➢ Other — this would include hazards inherent to the application itself like electric shock, arc flash, burns, fume, radiation, toxic substances, noise, etc. These hazards can arise from several sources and should be considered in a typical robot installation which include:

3.2. Control Errors

➢ These are faults within the control system of the robot like software errors, electrical interference, or faults in the hydraulic, pneumatic, or electrical sub-controls associated with the robot. Electrical interference can come from two sources — line noise and radiated frequency interference. Both types are hazards because they can cause erratic operation of microprocessor controlled robots.

3.3 VARIOUS SAFETY DEVICES:

- Presence Sensing Devices
- If an interlocked gate for access at load/unload station is not suitable, another alternative in guarding is to use presence sensing devices such as photoelectric light beams or pressure-sensitive mats. The advantage of these devices is that it is easier to gain access to the robot. When a presence sensing device is tripped, a separate actuation of the controls must be required to reactivate the robot working cycle. In Level 2 guarding within the work station perimeter where the operator has to enter the work envelope to carry out work frequently, the presence sensing device should be arranged to operate in the horizontal plane and cover a ground area. This can be done by horizontal light beams guards set around waist level which will be less prone to accidental damage. A low set of horizontal system has to detect narrow ankles rather than bulky waistlines and hence requires closer-set beams. The alternative to light curtains is to use pressure-sensitive, mats which are usually referred as a “Safety Mat”. These can be placed on the floor around the robot and when stepped on, turn the robot controller off or prevent the robot from cycle starting. A safety mat is a convenient way of guarding at the load/unload station and the only disadvantage is their susceptibility to damage depending on the condition of application.
- The photoelectric light beams guard and pressure sensitive mat must be of a fail to safety type. That is the control system as a whole, including machine safety system, is designed so that in the event of single component failure the overall safeguarding system will not fail to danger. Guidelines given in the Health and Safety Executive Guidance Note PM 41 and the BS 6491 should be followed for the installation and maintenance procedures of photoelectric light beam system. In general, presence sensing devices should only be used as a secondary forms of guarding or where limited access is required like at the load/unload stations. They can also be placed within the work station perimeter guarding in a high-risk installation to act as a back-up in the event of a failure in the interlock access gate.

- Trip Devices
- Trip bars and collision detector strip which works on a similar principle as that of the safety mat may be mounted on the robot arm itself for Level 3 guarding of smaller robots where operator has to stand at close proximity to the robot when it is idle. When depressed by contact with an obstruction, an impulse from the detector will cause, via a suitable interface, an emergency stop of the robot. Similarly, the collision detection device must be also a fail to safety type. The detector should be sufficiently sensitive to permit the robot arm movement to stop immediately.

- Emergency Stop Switches
- Emergency stop button and/or trip wires should be installed around the perimeter of the robot’s operating area in easily accessible locations as well as on the robot’s teach box and control console. Hitting the emergency button stops power to motors and causes the brakes on each joint to be applied immediately. All safety devices and stop buttons should be hard-wired to the robot controller and power brake system using hardware-based components and not part of the software or robot control programme, so that the robot can be stopped as quickly as possible.

- 3.4 ASSOCIATED SAFETY AND HEALTH

4. CURRENT RESEARCH ON ROBOTS

4.1While most robots today are installed in factories or homes, performing labor or life saving jobs, many new types of robot are being developed in laboratories around the world. Much of the research in robotics focuses not on specific industrial tasks, but on investigations into new types of robot, alternative ways to think about or design robots, and new ways to manufacture them. It is expected that these new types of robot will be able to solve real world problems when they are finally realized.

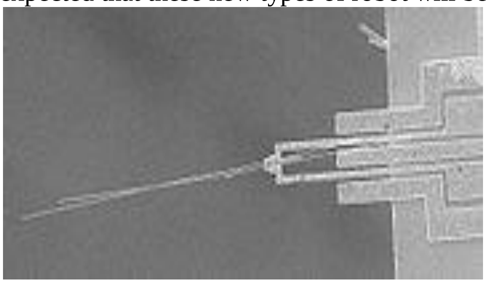


Fig. 4.1 A Micro fabricated electrostatic gripper holding silicon nano wires

- **Nano robots:** Nano robotics is the still largely hypothetical technology of creating machines or robots at or close to the scale of a nanometer (10^{-9} meters). Also known as nano robots or nanites, they would be constructed from molecular machines. So far, researchers have mostly produced only parts of these complex systems, such as bearings, sensors, and Synthetic molecular motors, but functioning robots have also been made such as the entrants to the Nano bot Robocup contest. Researchers also hope to be able to create entire robots as small as viruses or bacteria, which could perform tasks on a tiny scale. Possible applications include micro surgery (on the level of individual cells), utility fog, manufacturing, weaponry and cleaning. Some people have suggested that if there were nanobots which could reproduce, the earth would turn into "grey goo", while others argue that this hypothetical outcome is nonsense.
- Robots can be classified by their specificity of purpose. A robot might be designed to perform one particular task extremely as well, or a range of tasks less well. Of course, all robots by their nature can be re-programmed to behave differently,

but some are limited by their physical form. For example, a factory robot arm can perform jobs such as cutting, welding, gluing, or acting as a fairground ride, while a pick-and-place robot can

4.2 GENERAL-PURPOSE AUTONOMOUS ROBOTS

➢ General-purpose autonomous robots are robots that can perform a variety of functions independently. General-purpose autonomous robots typically can navigate independently in known spaces, handle their own re-charging needs, interface with electronic doors and elevators and perform other basic tasks. Like computers, general-purpose robots can link with networks, software and accessories that increase their usefulness. They may recognize people or objects, talk, provide companionship, monitor environmental quality, respond to alarms, pick up supplies and perform other useful tasks. General-purpose robots may perform a variety of functions simultaneously or they may take on different roles at different times of day. Some such robots try to mimic human beings and may even resemble people in appearance; this type of robot is called a humanoid robot.

5. ADVANTAGES

- It's a portable
  - Easy to design and fabricate.
- Very less maintenance.
- Its initial cost as well as running cost are less.

6. DISADVANTAGE

- Ultraviolet rays from arc welding;
- High-intensity light from laser beams
- Sparks from spot welding;
- Vapours from paint spraying.

7. APPLICATIONS

- General-purpose autonomous robots
- It is dedicated robots to use for safety purpose.
- It is used for Car production.

Automated guided vehicles (AGVs)

8. CONCLUSION

While most robots today are installed in factories or homes, performing labor or life saving jobs, many new types of robot are being developed in laboratories around the world. Much of the research in robotics focuses not on specific industrial tasks, but on investigations into new types of robot, alternative ways to think about or design robots, and new ways to manufacture them. It is expected that these new types of robot will be able to solve real world problems when they are finally realized

9. FUTURE SCOPE

Nano robotics is the still largely hypothetical technology of creating machines or robots at or close to the scale of a nanometer (10^{-9} meters). Also known as nano robots or nanites, they would be constructed from molecular machines. So far, researchers have mostly produced only parts of these complex systems, such as bearings, sensors, and Synthetic molecular motors, but functioning robots have also been made such as the entrants to the Nanobot Robocup contest. Researchers also hope to be able to create entire robots as small as viruses or bacteria, which could perform tasks on a tiny scale. Possible applications include micro surgery (on the level of individual cells), utility fog, manufacturing, weaponry and cleaning. Some people have suggested that if there were nanobots which could reproduce, the earth would turn into "grey goo", while others argue that this hypothetical outcome is nonsense..

REFERENCES

[1] Professor M.C. Bonney and Dr. Yong 1985: Robot Safety, International Manufacturing Technology, IFS Publications Ltd., UK. https://www.researchgate.net/publication/261726464_Safety_strategy_for_standardization_of_a_personal-AGV_robot
[2] R.D. Potter 1983: Safety for Robotics, Professional Safety, 1983
https://www.sciencedirect.com/science/article/abs/pii/016981419090016U
[3] N. Sugimato and K. Kawaguchi: Fault Tree Analysis of Hazards created by Robots. Institute of Industrial Safety, Tokyo, Japan.
[4] N. Percival 1984: Robot Safety, the Safety Practitioner, March 1984.