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Chapter 2

Techniques for the functioning of robots

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Abstract: Robotics is a scientific discipline focused on robots that execute tasks according to pre-established and adaptable programs and algorithms, either automatically or semi-automatically. These devices, generally referred to as robots, are either operated by people or function autonomously under the guidance of computer applications and algorithms. Robotics include the design, construction, and programming of robots. These robots directly interact with the physical environment and are frequently employed to do boring and repetitive jobs in lieu of humans. Robots can be classified according to their dimensions, application domain, or function as mentioned in this chapter. This chapter focuses on several topics related to robots, like; the functional elements of robots, anatomy of the robots, categories of robots, applications of robotics, challenges associated with robotics, robots influence on productivity, competitiveness and growth.

Keywords: Robots functioning, functional elements, anatomy of robots, categories of robots, applications, challenges, productivity, growth.

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2.1 Introduction

The fields of electrical engineering, mechanical engineering, computer science, and other related fields are all included in the field of robotics, which is a subfield of engineering and science. This division is responsible for the design, building, and usage of robots for controlling them, as well as sensory feedback and information processing as well. In the years to come, these are some of the technologies that will eventually replace humans and tasks performed by humans. The objective of these robots is to be utilized for any purpose, although they are currently being employed in sensitive situations for tasks such as bomb detection, deactivation of various explosives, and other similar tasks. Robots may take any shape, but a significant number of them have been designed to look like humans. It is possible that robots that have resemble the look of people would be able to walk like humans, speak like humans, have cognition like humans, and most crucially, be able to perform everything that humans are capable of doing. These days, the majority of robots are characterized as bio-inspired robots since they take their cues from the natural world. The subfield of engineering known as robotics is concerned with the conception, design, operation, and production of robots.

The following are features of robots:

(I) ***Robots possess a physical form:*** they are supported by their bodily structure and are propelled by their mechanical components. In the absence of physical form, robots will just function as software programs.

The brain of a robot is often referred to as the on-board control unit. This robot acquires information and transmits commands as output. With this control unit, the robot comprehends its tasks; otherwise, it would only function as a remote-controlled device.
(II) ***Sensors:*** These sensors in robots collect information from the external environment and transmit it to the central processing unit. Essentially, these sensors have circuits that generate voltage.

(III) ***Actuators:*** The components that facilitate the movement of robots and their parts are referred to as actuators. Examples of actuators include motors, pumps, and compressors. The brain instructs these actuators on when and how to react or move. Robots operate solely based on the instructions included inside their programming. These programs just instruct the brain regarding the timing of specific actions, such as movement and sound production. These programs just instruct the robot on using sensor data to make judgements.
(IV) ***Behavior:*** A robot's actions are determined by the program that has been developed for it. Upon the initiation of the robot's movement, it becomes readily apparent which type of software is being implemented within the robot. Fig. 2.1. illustrates a robot.

2.2 The Functional Elements of Robots

There are a great number of distinct kinds of robots, each of which fulfils a certain function and is utilized in a distinct setting. Electrical Components, Computer Programming Code, and Mechanical Structure are the three aspects that they share in common, despite the fact that they are very different from one another. Let’s go into further depth about these aspects in the following section:

Fig. 2.1. A robot.

(I) ***A Structure Made of Metal***: There is a mechanical structure present in every single robot. The frame and the mechanical components that are meant to accomplish a certain endeavor are included here. When the mechanical structure of the robot is being designed, the designer of the robot must take into consideration all of the essential mechanics and forces that will be applied to the robot because of its functioning.
(II) ***Electrical Components***: In order to give electricity and regulate the gear, a robotic system must include electrical components, which are essential. The electrical circuitry of robots can be fueled by either gasoline or batteries, and the robots themselves include devices that ensure power supply.

(III) ***Programming Code for Computers***: Every single robot has some kind of computer programming code embedded within it. The robot is essentially driven by the code, which is a collection of instructions that enables the electrical circuitry to connect with the mechanical components as well as the other components. The robot is able to plan out what it will do, when it will do it, and how it will do it thanks to a program. There are three ways to classify robotic programs, which are as follows: a) ***Remote Control (RC)***, b) ***Artificial Intelligence***, and c) ***Hybrid.***

(IV) ***Power Source***: Power is an essential component for each piece of robotic equipment. For a robot to function, it must have power. Several different sources of electricity can be utilized by robots. There are distinct advantages and disadvantages associated with each power source, which means that certain power sources are superior to others in certain contexts and applications.

(V) ***Actuators*** are the muscles of the robot that are responsible for converting electrical energy into the movement of the robot they are attached to. In addition, an actuator may be defined as a mechanical device that is accountable for the movement or propelling of something. One of the possible origins of this is an electric drive, such as a motor; another is a hydraulic drive; and a third is a pneumatic drive.

(VI) ***Sensors;*** the sensors are the window through which a robot may observe its surroundings. To be an active participant in its surroundings, a robot has to have the ability to sense. The concept of transduction, which denotes the process of converting one kind of energy into another, serves as the foundation for every sensor. In order to accurately evaluate the performance of sensors, the following aspects are very important:
a) ***Sensitivity*** is defined as the ratio of the change in output to the change in input.
b) ***Error or Accuracy*** can be defined as the difference between the output of the sensor and the actual value.

Caused by circumstances that may be adjusted for re-calibration, systematic or deterministic error, which is another type of error.

Also, random error is a type of error that can be caused by a variety of circumstances, including the instability of the camera, background noise, and other similar issues.
c) ***Reproducibility*** refers to the capability of reproduction of outcomes.
The ability to manipulate items, such as pick up, move, grasp, and so on, is essential for robots. This is the reason why the hands of the robot are referred to as end-effectors, while the arm that the end-effector is installed on is referred to as the manipulator instead. Programming the robot on a computer or training and teaching it to memorize actions and motions are two methods that may be utilized to manipulate the robot. In addition to mechanical and vacuum grippers, sanding wheels, and any other device that may be used to control a part, end-effectors can come in a wide variety of design configurations.
d) ***Locomotion***: Locomotion refers to the motorized movement of the robot in relation to its surroundings. Interaction forces, the mechanisms and actuators that create them, are the focus of this area of study. Locomotion may be broken down into several primary components: a. Stability, which includes the number of contact points, ii. center of gravity (C.O.G), iii. static/dynamic stabilization, and iv. the incline of the ground.

v. the characteristics of the environment, vi. the contact area, vii. the angle of contact, and viii. the frictional force

ix. the structure of the environment; x. the environmental medium (land, water, air). In order to get the robot to carry out any duties, it has to be commanded. Managing a robot may be broken down into three fundamental steps:

1. ***Perception; 2. Processing; 3. Taking action.***

Sensors or Sensitive devices are responsible for gathering data about the environment in real time, such as the location of a component in respect to the robot. This data is then processed and sent to the control system of the robot, where it is used to compute the relevant signals. After that, the information is released to the actuators, which are responsible for driving the mechanical structure of the robot. Different levels of autonomy can be possessed by control systems to robots:

1. ***Remote controlled robots***: The human has full control over the mobility of the robot, which is the first type of interaction.

2. ***Operator-assist robots***: The operator delivers medium- to high-level directives, and the robot determines how to carry them out on its own through calculation and analysis. 3. ***Autonomous robots***: the robot is able to carry out several tasks for lengthy periods of time without any input or cooperation from a human. Fig. 2.2. illustrates components of a robot.

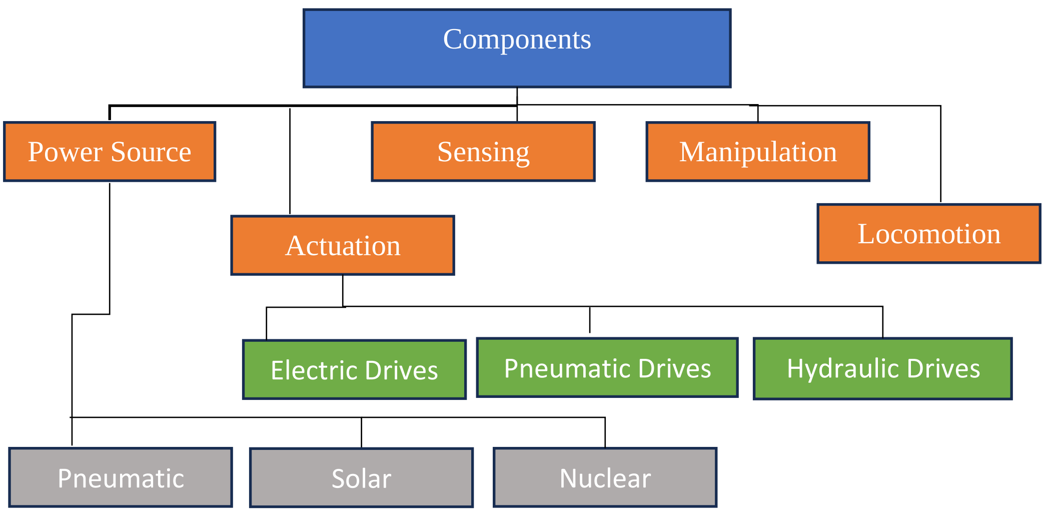


Fig. 2.2. Components of a robot

2.3 Anatomy of the Robots

Couples and Connections:

All of the joints and connections that make up the manipulator of an industrial robot are connected to one another. The field of anatomy is concerned with the study of various joints and connections, in addition to other features of the manipulator's body. A joint in a robotic system allows for relative motion to be transferred between two links of the robot. Every joint, also known as an axis, offers a certain degree of freedom (DOF) associated with motion. The vast majority of the time, there is just one degree of freedom that is connected to each joint. In light of this, the complexity of the robot can be based on the total amount of degrees of freedom that each individual possesses. There are two links that are linked to each joint; these are the input link and the output link.

The relative movement between the input link and the output link is regulated. A robotic link is the unmovable link. This element that is a part of the robot manipulator. The majority of the robots are affixed to a surface that is immovable. It is possible to recognise a joint-link numbering scheme based on this foundation, as demonstrated in Fig. 2.3.

In Fig 2.3. the name "link-0" refers to both the robotic base and the connection that it established with the first joint. To begin, the first joint is the first joint in the series. In joint-1, the input connection is denoted by link-0, while the output link is denoted by link-1. The first joint is the connection that leads to the second joint. Therefore, connection 1 is concurrently the output link for joint-1 with the same name in addition to the input connection for joint-2. More specifically, this joint-link-numbering approach is adhered to for each and every joint in the robotic systems, as well as linkages. The majority of industrial robots are equipped with mechanical joints, which may be categorised into the five categories listed below. The five categories of joints are shown in Fig. 2.4.

a) Linear joint, also known as a type L joint:

A translational movement is the movement that occurs between the input link and the output link relative to one another. Movement that is sliding, with the axes of the two links being parallel to one another.

b) Orthogonal joint: orthogonal joint, often known as a type U joint:

The input and output connections are different in this case, but the motion is still a translational sliding motion. Throughout the movement, they were perpendicular to one another.

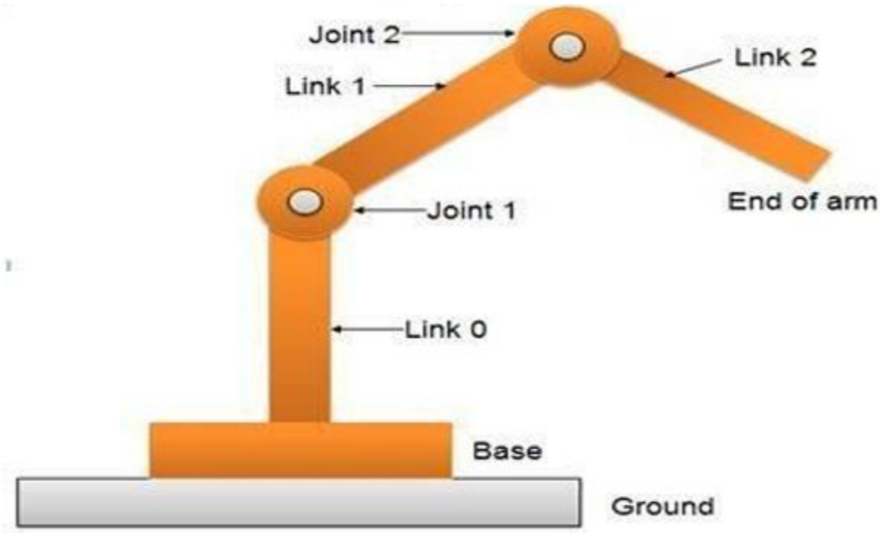


Fig. 2.3. Joint-link scheme for robot manipulator

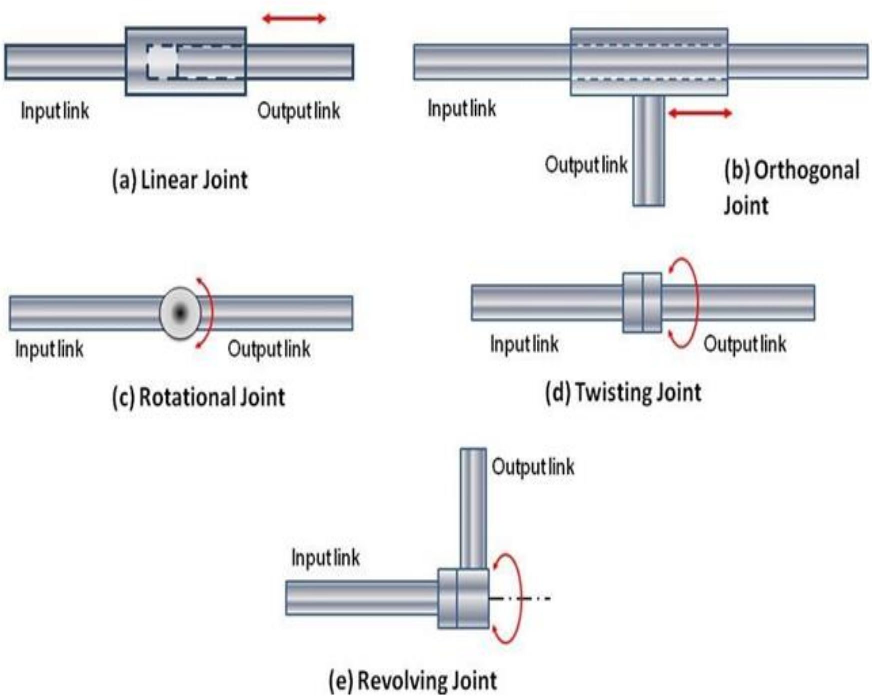


Fig. 2.4. Different types of joints

c) Rotational joint, also known as a type R joint :

The axis of rotation is perpendicular to the direction of rotation, thus this kind offers rotational relative motion. Both the input and output connections' axes are shown here.

d) Twisting joint, often known as a type T joint:

There is also rotational motion involved in this joint; however, the axis of rotation is parallel to the axes of another joint. Those are the two links.

e) A revolving joint, often known as a V-joint (the letter V for the "v" in "revolving"):

There is a sort of joint in which the axis of rotation of the joint is parallel to the axis of the input link. To be sure, the axis of rotation is perpendicular to the axis of the output connection on the output link.

Various configurations of robotic arms:

When it comes to body-and-arm arrangements, there are a great deal of distinct combinations that may be used. Robot manipulator with three degrees of freedom, which may be composed of any of the five different types of joints. All of the following are examples of common body-and-arm combinations.

1) The setup of the polar coordinate arm

2) An arrangement of the cylindrical coordinate arm

3) The arrangement of the Cartesian coordinate arm

4) A configuration with joined arms

5) The polar coordinate arm arrangement, often known as RRP

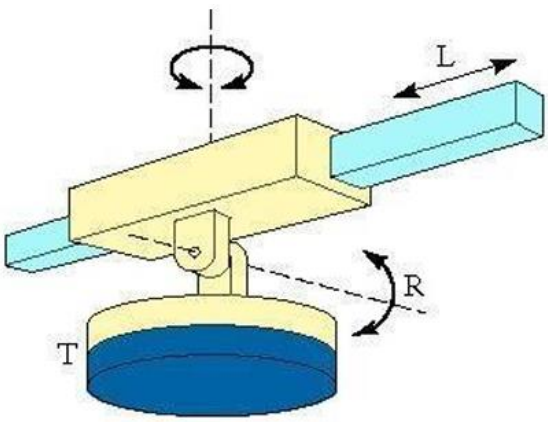


Fig. 2.5. DOF polar arm configuration

Figure 2.5. illustrates polar arm design with three degrees of freedom. Additionally, it is made up of a prismatic joint that is horizontal to revolute joint, it is possible to elevate or lower it. Both of the links are attached to a pair of base that rotates. The capacity to move the arm endpoint within a given range of motion is provided by these numerous joints.

Spherical partial space is spherical, and, this structure is referred to as a spherical coordinated configuration. It is this setup makes it possible to manipulate things that are lying on the ground.

Disadvantages:

- Low stiffness in mechanical terms
- Construction that is difficult to understand
- When the radial stroke is increased, the position accuracy drops even further.
- Among its applications are spray painting and machining.
- For instance, the MAKER 110 from the Unimate 2000 series
- Circular coordinate arm arrangement (RPP) is the second configuration

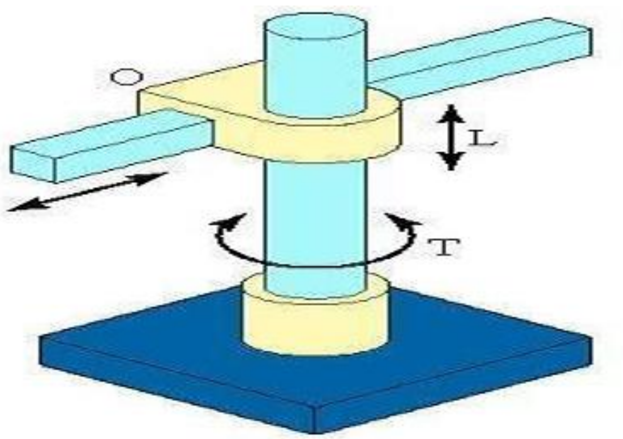


Fig. 2.6. DOF cylindrical arm configuration

Figure 2.6. illustrates configuration of a three-degree-of-freedom cylindrical arm, in the cylindrical arrangement, there are two prismatic joints that are perpendicular to one another and a revolute joint. A vertical column and a slide that can be moved back and forward are utilised in this setup in any direction along the column. There is a connection between the robot arm and the slide, which allows it to be moved in a radial direction with respect to table. By turning the column, the robot is able to accomplish a number of

different tasks in workplace with a shape that is similar to a cylinder. Good mechanical properties are offered by the cylindrical form.

As the horizontal stroke intensity increases, the accuracy of the stroke diminishes. In applications, it is possible to access limited horizontal capabilities, and it is therefore utilised for machine in the loading operations. The GMF model M-1A is an example.

The Cartesian coordinate arm arrangement with three degrees of freedom, often known as the PPP is shown in Fig 2.7. It is possible to establish a Cartesian coordinate or a rectangle coordinate configuration to produce exclusively linear motions along the three primary axes, by use of three slides that are perpendicular to one another.

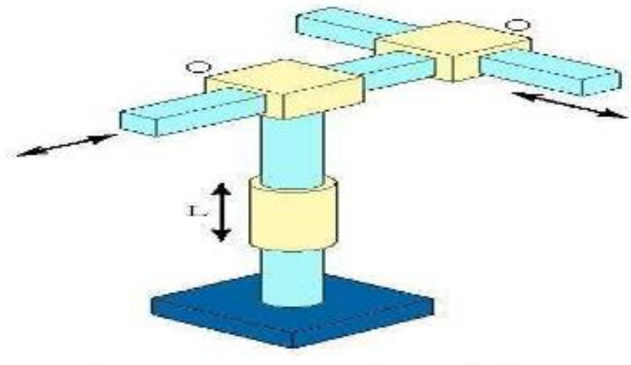


Fig. 2.7. DOF Cartesian arm configuration

It has three prismatic joints in its construction. The ends of the arm are able to function in a variety of locations. The space is cuboidal. It is simple to program the Cartesian arm, which provides a high level of accuracy.

Disadvantages:

- A limited degree of manipulability
- A lack of agility, thus they are unable to move effortlessly and rapidly

Examples of applications include lifting and moving big loads. IBM RS-1 is an example.

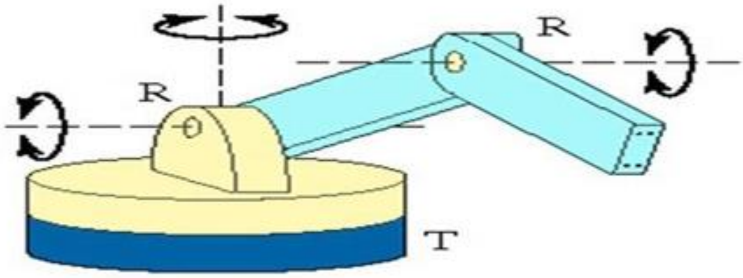


Fig. 2.8. DOF joined arm configuration

Fig. 2.8 illustrates jointed arm arrangement with three degrees of freedom. The configurations of jointed arms are comparable to those of the human fingers. It is made up of joints, and the human forearm and upper arm are represented by two straight links, and there are two rotational joints to connect them. This pair is affixed to a rotating table that is positioned vertically, that corresponds to the joint in the human waist. There is a spherical-shaped work volume. The structure in question is the most one that is dexterous. The use of this setup is quite widespread. Among the applications are spray painting and arc welding. SCARA robot, which stands for selective compliance assembly robot arm, is an example. "Selective Compliance Assembly Robot Arm" is the whole definition of this term. In terms of construction, it is comparable to the robot with a jointed arm, with the exception that the rotational axes of the shoulder and elbow are vertical. In the horizontal direction, the arm presents a degree of compliance, however in the vertical direction, it is quite stiff.

In most cases, the SCARA body-and-arm arrangement does not make use of a separate wrist component. When doing insertion-type assembly procedures, the typical operating environment is one in which wrist joints are involved. Similar to the wrist-joint arrangement, the other four body-and-arm combinations are more or less similar configuration by employing a wide variety of combinations of rotary joints, including among others. R and T are the types.

Wrist of a Robot:

Attached to the terminus of the arm is the wrist assembly. It is possible to attach end effectors to the wrist assembly. In order to orient end effectors, the wrist assembly serves as a function. Global position is determined by the body and the arm pertaining to the end effector. It possesses three degrees of freedom. The roll (R) axis is a mechanism that includes the rotation of the wrist mechanism around the arm axis. The pitch (P) axis is a rotation of the wrist that revolves either upwards or downwards. Yaw (Y) axis refers to the rotation of the wrist in either the right or left direction. The robot wrist assembly can have either two or three degrees of freedom, depending on the situation.

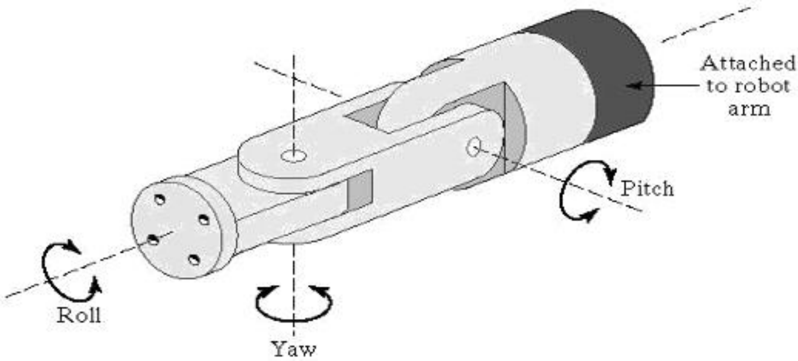


Fig. 2.9. Robotic wrist

Figure 2.9 includes a representation of the degree-of-freedom wrist joint. The roll joint is achieved by the utilisation of the T joint, the pitch joint, which is accomplished by utilising a R joint, and the yaw joint, which is a right-and-left alignment joint. Installing a second R joint allows for the acquisition of motion. A careful approach is required in order to avoid pitch confusion. R joints are utilised in both yaw movements and yaw motions.

A mechanical system's degree of freedom (DOF) is the number of different ways in which it may be manipulated. The setup of the system is defined by separate parameters. The quantity of parameters is what determines the ability to ascertain the condition of a physical system, which is essential for the examination of the systems that make up bodies. There are three components that determine the location and orientation of a rigid body in space which are as follows: translation as well as rotation, and a total of six degrees of freedom.

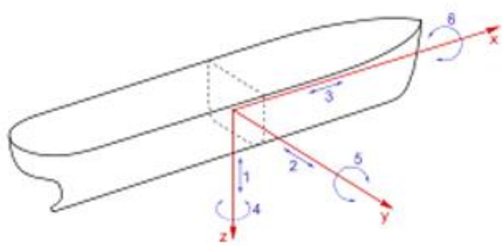


Fig.2.10. Six degrees of freedom of movement of a ship

Figure 2.10. illustrates six degrees of freedom of movement of a ship. When it comes to mobility, a ship has six degrees of freedom. The movement of a ship when it is at sea is characterised as having six degrees of freedom, just like the motion of a solid body.

A translation depends on:

1. Heaving, or the act of moving up and down;

2. Vibrating to the left and right (swaying);

3. advancing and regressing (also known as "surging-like")

In rotation:

1. pitching occurs when the tilt is forward and backward;

2. Yawns to the left and right from the centre;

3. Rolls from side to side when pivoting.

Based on Fig. 1.9, each of the three degrees of freedom that make up the trajectory of an aeroplane in flight is as follows:

- Three degrees of freedom are associated with attitude along the trajectory, bringing the total number of degrees of freedom to six.

Fig.2.11. Attitude degrees of freedom for an airplane

Degrees of flexibility for an airplane's attitude are depicted in Fig.2.11. The term "work volume" refers to the area on which a robot is able to move and function, specifically its wrist end. The work space and the work envelope are two more names for this object. In order to achieve a higher level of work volume, the following are some of the physical aspects of a robot that should be taken into consideration:

- The anatomy of each of the many robots
- The highest possible value for the movement of a robot joint
- The dimensions of the robot's components, such as the wrist, arm, and torso

Generally speaking, an industrial robot is a programmed machine that is capable of performing a variety of tasks. The features that are anthropomorphic, are also known as human-like characteristics that are similar to human characteristics, either have a physical structure, or make it possible for the robot to react to sensory signals in a manner that is comparable to human beings. Among these human qualities are mechanical arms, which may be utilised for a variety of purposes. Jobs in the industrial sector, or sensory perceptive equipment, such as sensors, enable robots to do tasks and interact with other machines, as well as make judgements that are straightforward. Robotics and numerical control are comparable in the sense that both of these approaches aim to achieve coordinated control of a number of movable axes, which are referred to as joints in robotics. Robots, on the other hand, are intended to participate in a wider range of activities than only numerical control. Applications such as spot welding, material transfer (pick and place), machine loading, and other similar tasks are typical examples, as well as assembly and spray painting. The advantages that robots provide in terms of both technology and business in general are numerous.

2.4. Categories of Robots

2.4.1. Industrial Robots

Industrial automatons. robots are used for painting and welding. Robot painting is consistent, homogeneous, and characterised by great quality and accuracy. Robots can access extremely challenging locations due to their superior flexibility, a task that poses difficulties for people. An individual must transport a large spray gun and don a mask for protection against hazardous chemicals. The repetition rate of a robot is elevated due to its lack of weariness. The safety levels attainable through the use of robots are elevated, since they protect humans from exposure to noxious chemical toxins.

Basic Types of Industrial robots:

Classification by mechanical structure:

• ***Articulated robot:*** a robot whose arm has at least three rotary joints

• ***Cartesian (linear/gantry) robot:*** robot whose arm has three prismatic joints and whose axes are correlated with a cartesian coordinate system

• ***Cylindrical robot:*** a robot whose axes form a cylindrical coordinate system

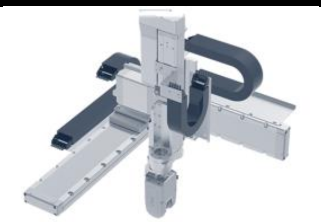
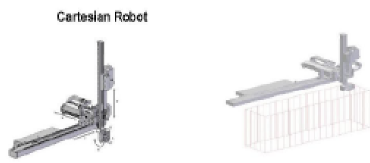
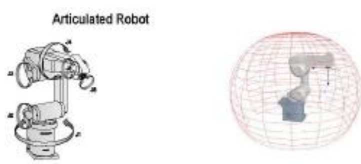
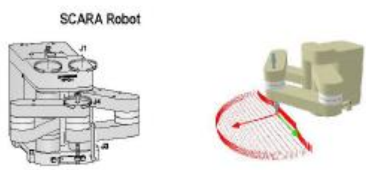
• ***Parallel robot:*** a robot whose arms have concurrent prismatic or rotary joints

• ***SCARA robot:*** a robot, which has two parallel rotary joints to provide compliance in a plane

• ***Others:*** Robots not covered by one of the above classes

Table 2.1. illustrates the mechanical configuration and kinematics of these types of robots, and Table 2.2. illustrates robots characteristics.

Table 2.1. Robots Kinematic Structure

name	Photo	Kinematic Structure
Cartesian Robots		
Articulated Robots		
SCARA Robots		

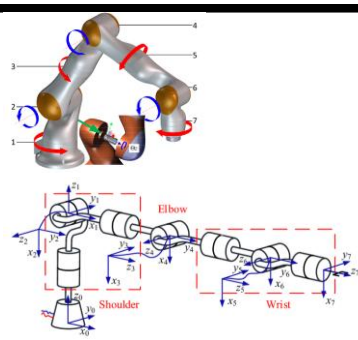
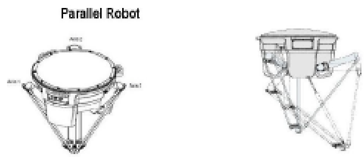
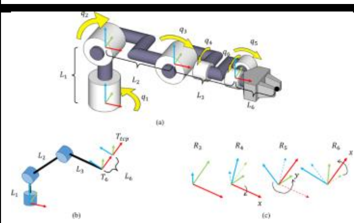
Collaborative Robots		
Delta Robots		
Polar Robot		
Cylindrical Robots		

Table 2.2. Robots characteristics

name	Characteristics

Cartesian Robots	• Also called linear or gantry robots • Moves in straight lines on 3-axis • Highly flexible in configurations, easy to adjust speed precision, stroke length and size • Used for CNC machines and 3D printing
Articulated Robots	• Resembles a human arm that is mounted to a base with a twisting joint • Can have two rotary joints to ten rotary joints which act as axes • Utilize 4 to 6 axis • Used for assembly, arc welding, material handling, machine tending, packaging
SCARA Robots	• Selective Compliance Assembly (or Articulated) Robot Arm • Functions on 3-axis and have rotary motion and excel in lateral movements • Easier integration than cartesian robots • Used for assembly, palletizing and bio-med applications
Collaborative Robots	• Also called cobots, linear or gantry robots • Move in straight lines on 3-axis • Used for pick and place, palletizing, quality inspection, and machine testing
Delta Robots	• Parallel robots that possess three arms connected to a single base, which is mounted above the workplace • Moves delicately and precisely at high speeds • Used for food, pharmaceutical, electronic industries
Polar Robot	• Spherical robots with an arm with two rotary joints and one linear joint • Axes work together to form a polar coordinate • Used for die casting, injection molding, welding, material handling
Cylindrical Robots	• Rotary joint at the base and a guided thrust block to connect the links • Cylindrical shaped work envelop rotating shaft and extendable arm that moves in a vertical and sliding motion

	• Used for tight workplaces and simple assembly, machine tending, coating applications

2.4.2. Surgical medical robots

Benefits of a medical robot include that the patient has rapid recovery. The procedure exhibits enhanced precision with reduced errors. The robot can do minor incisions in the body and execute significant surgeries with minimum harm to the patient. Consequently, the recuperation duration is reduced. The apparatus is more sanitary and secure.

2.4.3. Mobile robots

Mobile robot equipped with legs or wheels are used for chemical power plants, underwater or in distant places, and bomb-laden fields. The advantage of a legged robot is its ability to circumvent barriers, which may pose hazards such as explosives, and to safeguard things from potential damage caused by the robot's movement.

2.4.4. Unmanned aerial robots

Unmanned aerial and maritime vehicles operated remotely from a base station, can be utilised for military or rescue operations.

2.4.5. Robotic Toys

Robotic Toys are used for Amusement.

2.4.6. Robotic Cleaning Solutions

Robotic Cleaning Solutions are implemented for Domestic and Industrial Applications.

Table 2.3. illustrates advantages and disadvantages of robots.

Table 2.3. Advantages and Disadvantage of robots

Advantages	Disadvantages

- Flexibility and re-programmability - Improved product quality and reproducibility - Maximum capacity utilization - multiple shifts - Accident reduction - Reduced work stoppages	- Human labor gets replaced - Increased unemployment - socio-economic turmoil - Retraining cost for highly skilled labor - Huge capital investment

2.4.7. Microrobotics

The accomplishments of miniaturisation are increasingly apparent in daily life; miniaturised devices are found in a growing array of applications, particularly in electronic devices—such as smartphones, laptops, vehicle sensors, and household items—as well as in biological probes, medical systems, and military equipment. This development in robotics results in creative solutions across various application domains, including industrial maintenance and inspection, non-invasive surgical procedures in medicine, and micro-operations in biology. Miniaturised robots, owing to their diminutive dimensions, may execute tasks in confined locations that are inaccessible to humans. Microrobotics remains a highly promising area of research despite the development of multiple prototypes (Caprari et al., 2002; Kernbach et al., 2009; Mondada et al., 2009; Rubenstein, et al., 2012).

Microrobotics is frequently cited as a component of the Industry 4.0 technology suite, which also encompasses sensors, drones, virtual and augmented reality, and additive manufacturing—capable of addressing the difficulties posed by the Sustainable Development Goals established by the United Nations (Kumar and Nayyar, 2020). In the literature, the term microrobot denotes a diverse array of robotic systems. It is typically used to all types of robots that execute tasks in the microworld.

Nevertheless, the name microrobots is more accurately applied to miniature robots whose dimensions are on the scale of several cubic centimetres. The justification for this expansive meaning of the term is that both groups encounter several principal challenges, like; non-intuitive physics, complex production, and observation difficulties. Similar to traditional robots, microrobots are integrated systems comprising sensors, actuators, and a logic circuit.

The primary challenge in microrobot development is the manufacture of micro-actuators and micro-sensors that provide great efficiency and stability. Sensors suitable for confined spaces frequently lack precision, resulting in incomplete environmental knowledge, necessitating the control system to manage this deficiency. Furthermore, microcontrollers typically lack the processing power and memory prevalent at the macroscale (Zhu et al., 2008). Consequently, streamlined control techniques are typically used at the microscale. Mechanics are inherently more resilient at the microscale; this benefits microrobots by allowing space conservation for essential components.

The assembly of diminutive components is another pertinent concern for microrobots. The implications of scale and the resulting dominance of surface forces influence the functionality of a micromanipulator (Ghosh, 2011). The release phase of manipulation is crucial, and several ways have been examined and evaluated. In micromanufacturing, each technique possesses distinct advantages and disadvantages, rendering certain methods more appropriate for specific applications than others.

2.5. Applications of Robotics

Robotics is applicable across several disciplines, and its adaptability enables utilisation in multiple industries. Robots are extensively utilised in automotive assembly lines for welding, painting, pick-and-place operations, and quality assurance.

- ***Healthcare:*** Robots assist surgeons during operations, facilitating expedited recovery. Robotic exoskeletons facilitate rehabilitation and aid patients in recovering movement following injuries. Telemedicine robots facilitate remote consultations, essential in regions with restricted medical access. For instance, Toyota's healthcare assistants exemplify robots facilitating walking recovery.
- ***Logistics:*** Warehouse robots oversee inventory management, sorting, and packaging, enhancing efficiency. Autonomous Mobile Robots (AMRs) traverse warehouses, augmenting efficiency.
- ***Agricultural robots*** facilitate planting, harvesting, and crop monitoring, hence enhancing precision farming. Autonomous tractors facilitate planting and harvesting, whereas agricultural drones inspect fields for crop health evaluation.
- ***In the retail and hotel sectors***, robotics improve customer experience by automating inventory management, offering wayfinding assistance, and aiding with baggage or parking valet services.
- ***Robots enhance experiential learning*** and actively involve students in STEM disciplines. For instance, Softbank Robotics created the Nao model for the L2TOR European research initiative, aimed at instructing young children in a second language.
- ***Space:*** Robotic technology is crucial for space research as it facilitates the investigation of asteroids, moons, and other celestial bodies. Rovers like as NASA's Curiosity investigate planetary surfaces, gathering data and materials.

- ***Defence and security:*** Military and security applications include bomb disposal robots, surveillance drones, and autonomous vehicles for reconnaissance in perilous areas.
- ***Intelligent urban areas:*** Robotics improve safety and operational efficiency.
- ***Humanoid robots*** provide navigation and informational services.
- ***Autonomous Mobile Robots (AMRs)*** transport items and provide regular security surveillance. Robotics accelerate construction by doing site surveys and gathering building modelling data. Welding Regarded as a perilous undertaking for humans because to the production of poisonous gases. The welding task is notably challenging for an individual tasked with joining two pipes from varying sides and angles while maintaining an uncomfortable stance for an extended duration. It might adversely affect one's physique and lead to health issues for the worker. The challenge for a person is to view all sides of welded structures when welding around a pipe, as only one side of the pipe is visible at a time. Painting presents analogous issues to welding owing to the utilisation of hazardous chemical substances.
- ***Assembly operation:*** The assembly of a chip necessitates extreme precision due to the delicate wires involved, which need meticulous and correct jobs that are beyond human capability, however are easily managed by a robot.
- ***Dealing with chemicals:*** A robot can attain consistent quality at elevated standards. A robot may be reprogrammed several times to attain a level of excellence that is typically unattainable by humans. Safety is paramount when a robot manages chemicals, biochemicals, poisonous substances, and nuclear materials. They can be managed with utmost safety and efficiency, alleviating humans from engaging in high-risk, stress-inducing tasks. Robots can meticulously manipulate delicate and minuscule components, including glass, microscopic chips, and cables.
- ***Inspection and maintenance operations in hazardous environments:*** for instance, managing explosives, investigating the deep sea, outer space, and other celestial bodies. An instance is the wrecked Titanic. A robot was employed to ascertain the ship's contents, as it rested at a depth beyond human accessibility.
- ***Space missions:*** to collect samples from extraterrestrial bodies and to analyse them from afar.

2.6. Challenges Associated with Robots

Notwithstanding the substantial progress in robotics, many problems remain that must be resolved to guarantee the safe and dependable implementation of robots in practical applications.

- ***Safety concerns:*** Accidents involving industrial robots can be lethal. Enhanced safety measures and improved human-robot collaboration techniques are essential. In 2015, a worker at a car assembly facility was reportedly killed by a robot.
- ***Ethical considerations:*** AI-driven robots provoke ethical dilemmas, including autonomous weaponry and algorithmic prejudices. Challenges in healthcare and law enforcement ethics are substantial.
- ***Cybersecurity threats:*** Enhanced connectivity renders robots susceptible to cyber assaults. In 2017, the "WannaCry" ransomware assault impacted a robotic manufacturing factory.
- ***Data and algorithmic bias:*** Robots educated on extensive datasets may reinforce societal biases. In 2019, some facial recognition algorithms shown prejudice in gender identification.
- ***Job displacement:*** Automation in industries results in job loss. In industry, robots have resulted in job displacement, leading to socio-economic difficulties. Goldman Sachs projects that 300 million employment may be eliminated or degraded due to this rapidly advancing technology.
- ***Financial constraints and accessibility:*** Elevated development expenses restrict the accessibility of robotics, particularly in smaller sectors or emerging areas.
- ***Regulatory frameworks:*** The absence of established rules generates apprehensions regarding safety, liability, and ethical utilisation. Explicit directives for the development and implementation of robotic systems are essential.

2.7. Robots, Productivity, Competitiveness and Growth

Robots enhance productivity when utilised for jobs they execute more efficiently and with superior, consistent quality compared to people. In a study conducted by Georg Graetz and Guy Michaels at the Centre for Economic Performance, London School of Economics, it was determined that the densification of robots enhanced annual GDP growth and labour productivity by approximately 0.37 and 0.36 percentage points, respectively, from 1993 to 2007 across 17 countries. This accounted for 10% of the total GDP growth in these nations during the specified period, in contrast to the 0.35 percentage point estimated contribution of steam technology to British annual labour productivity growth between 1850 and 1910 (Graetz and Michaels, 2015).

A recent study conducted by Centre for Economics and Business Research in 2017 revealed that investment in robotics accounted for 10% of GDP per capita growth in OECD countries from 1993 to 2016. The study indicated that a one-unit rise in robotics density, defined as the number of robots per million hours worked, correlates with a 0.04% enhancement in labour productivity. The McKinsey Global Institute forecasts that automation will account for up to 50% of the necessary productivity gains to achieve a 2.8% GDP increase over the next 50 years (McKinsey Global Institute, 2017).

An Accenture analysis, in partnership with Frontier Economics, predicts that automation could treble Gross Value Added (GVA) in 12 major economies by 2035, with labour productivity enhancements reaching 40% (Accenture, 2016). The Boston Consulting Group predicts a 30% enhancement in productivity over the next decade, mostly driven by the increased adoption of robots in small and medium-sized enterprises, as these robots become more cost-effective, versatile, and user-friendly to program (Boston Consulting Group, 2015).

Enhanced productivity is allowing certain companies, including Whirlpool, Caterpillar, Ford Motor Company in the United States, and Adidas in Germany, to reorganise their supply chains by relocating segments of the production process to the place of origin. Citigroup and the Oxford Martin School indicate observable indicators of a deceleration in the fragmentation of goods production, identifying robot density as a significant catalyst in this trend. A poll of 238 Citigroup clients revealed that 70% expected automation will prompt enterprises to relocate their manufacturing domestically and centralise operations (Citi and Oxford Martin School, 2016). The Reshoring Initiative in the United States estimates that 250,000 jobs have been returned to the country through reshoring and inward foreign direct investment since 2010 (Reshoring Initiative, 2015). Automation not only facilitates reshoring, but companies that utilise robots are also less inclined to relocate or offshore initially, as indicated by a report for the European Commission by the Fraunhofer Institute for Systems and Innovation Research (European Commission, 2015). Reshoring offers national benefits, including possible demand spillovers to other sectors and the consolidation of specialised manufacturing expertise, which is essential for attracting and developing people, as well as enhancing national competitiveness.

Productivity enhancements from robots and automation are significant not only for individual companies but also for industry and national competitiveness. Since the financial crisis, both US manufacturing productivity and industrial production have consistently increased (PwC, 2016). A Barclays analysis estimates that enhanced investment in robotics may elevate manufacturing Gross Value Added in the UK by 21.0% over a decade (Barclays, 2015). According to Boston Consulting Group (BCG), South Korea, possessing the highest robot density, is anticipated to enhance its manufacturing cost competitiveness by 6 percentage points compared to the US by 2025, provided that all other cost determinants remain constant (Boston Consulting Group, 2015).

Ultimately, a correlation exists among productivity, corporate competitiveness, and heightened demand, (Graetz and Michaels, 2015). An increase in production that leads to wage growth or overall employment expansion results in heightened demand that permeates other sectors of the economy (Zierahn et al., 2016), establishing a virtuous cycle of enhanced productivity, elevated demand, increased wages, and augmented purchasing power, which in turn generates further demand for additional products and sectors. Economist Tyler Cowen observes that manufacturing, specifically, appears to generate significant spillover effects, both inside the industry and in related industries (Cowen, 2016).

Automation is transforming demand by facilitating enhanced personalisation and mass customisation. Robots are utilised in a business to manufacture customised flip-flops according to 3D laser scans of consumers' foot (International Federation of Robotics, 2016). This degree of customisation would not be attainable without advancements in automation technologies.

Conclusions

The development of robotic technology has led to an increase in the number of jobs that are being carried out by robots. This is done in order to cut down on the amount of time required for execution and to reduce the number of errors that are created by humans, such as slips that are the result of weariness or ignorance. By executing a task continually until it is shut down for maintenance or until it has completed the work that was given to it, the utilisation of robots will also minimise the amount of downtime that occurs. Therefore, having robots means that company owners may be more competitive. This is because robots are capable of performing occupations more effectively and more quickly than people are. For example, a robot can build and assemble an automobile. Although robots are not yet capable of performing every task, their current functions include providing assistance to research and industry. At long last, as technological advancements continue to be made, new applications of robots will emerge, bringing with them fresh opportunities and new possibilities.

References

Accenture.(2016). *Why Artificial Intelligence Is the Future of Growth.* Accenture.

Barclays. (2015). *Future-proofing UK manufacturing.* Barclays.

Boston Consulting Group. (2015). *The Robotics Revolution.*

Caprari, G., Estier, T., & Siegwart, R. (2000). Fascination of down scaling-Alice the sugar cube robot. In IEEE International Conference on Robotics and Automation (ICRA 2000): Workshop on Mobile Micro-Robots.

Citi and Oxford Martin School. (2016). *Technology at Work V2.0.*

Cowen, T. (2016, April). Economic development in an "average is over" world.

European Commission. (2015). *Analysis of the impact of robotic systems on employment in the European Union.* Luxembourg: Publications Office of the European Union.

Ghosh, A. (2011). Scaling laws. Mechanics over micro and nano scales, 61-94.

Graetz, G., & Michaels, G. (2015). Robots at work. Centre for Economic Performance, London School of Economics. discussion paper 1335. Disponible en: http://cep. lse. ac. uk/pubs/download/dp1335. pdf [Consulta: 29 de diciembre 2016].

Gregory, T., Salomons, A., & Zierahn, U. (2016). Racing with or against the machine? Evidence from Europe. Evidence from Europe (July 15, 2016). ZEW-Centre for European Economic Research Discussion Paper, (16-053).

International Federation of Robotics. (2016). *World Robotics Industrial Robots 2016.*

Kernbach, S., Thenius, R., Kernbach, O., & Schmickl, T. (2009). Re-embodiment of honeybee aggregation behavior in an artificial micro-robotic system. Adaptive Behavior, 17(3), 237-259.

Kumar, A., & Nayyar, A. (2020). si 3-Industry: A sustainable, intelligent, innovative, internet-of-things industry. A roadmap to Industry 4.0: Smart production, sharp business and sustainable development, 1-21.

McKinsey Global Institute. (2017). *A Future That Works: Automation, Employment and Productivity*.

Mondada, F., Bonani, M., Raemy, X., Pugh, J., Cianci, C., Klaptocz, A., ... & Martinoli, A. (2009). The e-puck, a robot designed for education in engineering. In Proceedings of the 9th conference on autonomous robot systems and competitions (Vol. 1, No. 1, pp. 59-65). IPCB: Instituto Politécnico de Castelo Branco.

PwC. (2016). *Upskilling manufacturing: How technology is disrupting America's industrial labor force.* Price Waterhouse Coopers in conjunction with the Manufacturing Institute.

Reshoring Initiative. (2015). *Reshoring Initiative Data Report 2015*. reshorenow.org. http://reshorenow.org/content/pdf/2015_Data_Summary.pdf.

Rubenstein, M., Ahler, C., & Nagpal, R. (2012, May). Kilobot: A low cost scalable robot system for collective behaviors. In 2012 IEEE international conference on robotics and automation (pp. 3293-3298). IEEE.

Zhu, T. T., Bushby, A. J., & Dunstan, D. J. (2008). Materials mechanical size effects: a review. Materials Technology, 23(4), 193-209.