

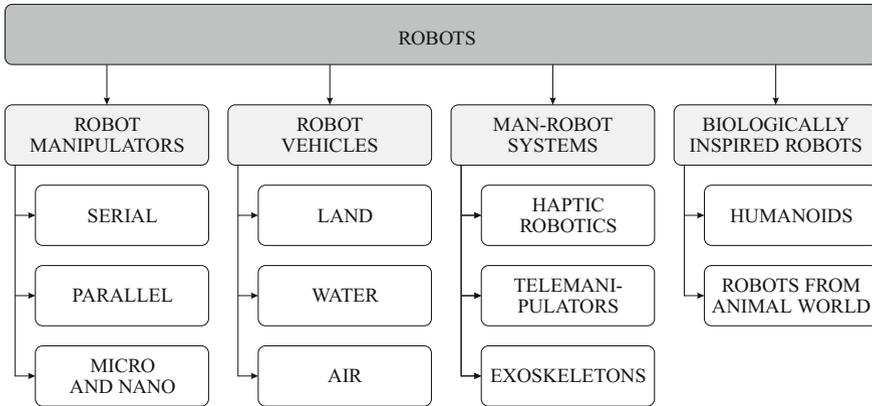
# Chapter 1

## Introduction



Today's robotics can be described as a science dealing with intelligent movement of various robot mechanisms which can be classified in the following four groups: robot manipulators, robot vehicles, man-robot systems and biologically inspired robots (Fig. 1.1). The most frequently encountered robot manipulators are serial robot mechanisms. The robot manipulator is represented by a serial chain of rigid bodies, called robot segments, connected by joints. Serial robot manipulators will be described in more details in the next section of this chapter. Parallel robots are of considerable interest both in science and in industry. With these, the robot base and platform are connected to each other with parallel segments, called legs. The segments are equipped with translational actuators, while the joints at the base and platform are passive. Parallel robots are predominantly used for pick-and-place tasks. They are characterized by high accelerations, repeatability, and accuracy. As the robot manipulators replace the human operator at various production jobs, their size is often similar to that of a human arm. Manufacturers can also provide robot manipulators which are up to ten times larger, capable of manipulating complete car bodies. By contrast in the areas of biotechnology and new materials micro- and nanorobots are used. Nanorobots enable pushing, pulling, pick-and-place manipulations, orienting, bending, and grooving on the scale of molecules and particles. The most widespread nanomanipulator is based on the principle of atomic force microscope. The actuator of this nanomanipulator is a piezoelectric crystal, the movement of which is assessed by the use of a laser source and photocell.

Autonomous robot vehicles are found on land, in the water and in the air. The land-based mobile robots are most often applied in man-made environments, such as apartments, hospitals, department stores, or museums, but can increasingly be found on highways and even pathless grounds. Most mobile robots are nevertheless used on flat ground with movement enabled by wheels, with three wheels providing the necessary stability. Often the wheels are specially designed to enable omnidirectional movements. Robot vehicles can be found as vacuum cleaners, autonomous lawn mowers, intelligent guides through department stores or museums, attendants



**Fig. 1.1** Classification of robots

in clinical centers, space rovers, or autonomous cars. Students can enjoy learning in various competitions, for example football or rescue games, based on the use of small mobile robots. Among the aerial vehicles, the most popular appear to be small quadcopters. They have a very simple mechanical structure what makes them comparatively inexpensive. Quadcopters fly using four rotors and are equipped with sensors such as gyroscopes, accelerometers, and cameras, and mostly used for surveillance purposes. Larger autonomous versions are used for military reconnaissance missions. Water-based robots either float on the surface or operate under water. The underwater versions can have the shape of smaller autonomous submarines. They can often be equipped with a robotic arm and used in ocean research, sea floor or ship wrecks observation or as attendants on oil platforms. Autonomous floating robots are used for marine ecological assesments.

New knowledge in the area of robot control is strongly influencing the development of man-robot systems, such as haptic robots, telemanipulators, and exoskeletons. The use of haptic robots is related to virtual environments which are usually displayed on the computer screens. Early virtual environments provided sight and sound to the observer, but no sense of touch. Haptic robots provide the user with the feeling of touch, limited motion, compliance, friction, and texture in virtual environment. Haptic robots play an important role in rehabilitation robotics, where small haptic robots are used for the assessment and evaluation of movements of the upper extremities in paralyzed persons. Stronger haptic systems can hold the wrist of a paralyzed person and guide the arm end-point along the desired path which is shown to the subject in a virtual environment presented on the computer screen. The haptic robot exerts two types of the forces to the subject's wrist. When the patient is unable to perform a movement along the path shown to him in the virtual environment, the robot pushes the wrist along the required trajectory and helps the patient to accomplish the task. The robot is helping only to the extent necessary for the patient to reach the goal point. When the patient's paralyzed extremity travels away from the

planned curve, the robot pushes the wrist to the vicinity of the required trajectory. Telemanipulators are robots which are controlled by a human operator when there is a barrier between the telemanipulator and the human operator. The barrier between the operator and working environment is usually either distance (e.g. outer space) or dangerousness (e.g. inside a nuclear plant). Telemanipulators are also entering the medical world, being used in surgery (telemedicine). Exoskeletons are active mechanisms which are attached to human upper or lower extremities. They are mainly used for rehabilitation purposes. Lower limb exoskeletons may increase the strength of healthy persons or enable the retraining of paralyzed persons in walking. In comparison with haptic rehabilitation robots, exoskeletons for upper extremities exert forces to all segments of paralyzed arm.

Biologically inspired robots can be divided into humanoid robots and the robots from the animal world. Examples from the animal world are various types of robotic snakes, fish, quadrupeds, six- or eight leg walking robots. Humanoid robots are by far the most advanced robot systems in the group of the biologically inspired robots. They are designed to live and work in a human environment. The most noticeable property of humanoid robots is their ability of bipedal walking. They walk either with statically stable or dynamically stable gait, they can balance while standing on a single leg, they move in accordance with human co-worker, they can even run. The current problems in humanoid robotics are related to artificial vision, perception and analysis of environment, natural language processing, human interaction, cognitive systems, machine learning and behaviors. Some robots also learn from experience replicating natural processes such as trial-and-error and learning by doing, in the same way a small child learns. In this way the humanoid robot gains a certain degree of autonomy which further means that humanoid robots can behave in some situations in a way that is unpredictable to their human designers. Humanoid robots are coming into our homes and are becoming our partners. They may soon be companions to the elderly and children, assistants to nurses, physicians, firemen, and workers. The need is arising to embody ethics into a robot, which is referred to as robo-ethics. Robo-ethics is an applied ethics whose objective is to develop scientific/cultural/technical tools that can be shared by different social groups and beliefs. These tools aim to promote and encourage the development of robotics for the advancement of human society and individuals, and to help preventing its misuse against humankind. In 1942 the outstanding novelist Isaac Asimov formulated his famous three laws of robotics. Later, in 1983, he added the fourth law, known as the zeroth law: *No robot may harm humanity or through inaction, allow humanity to come in harm.* The new generation of humanoid robots will be partners that coexist with humans assisting them both physically and psychologically and will contribute to the realization of a safe and peaceful society. They will be potentially more ethical than humans.

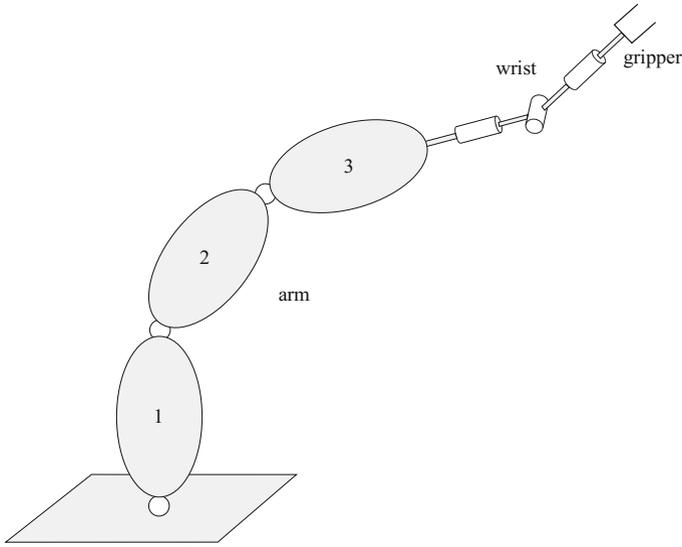
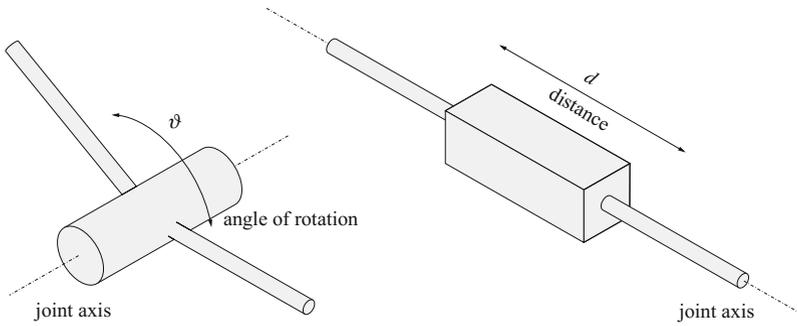


Fig. 1.2 Robot manipulator

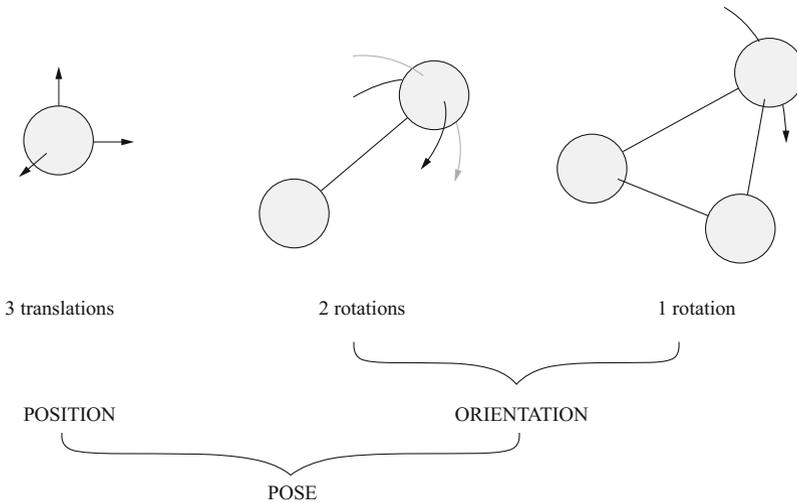
## 1.1 Robot Manipulator

Today the most useful and efficient robotic systems are the industrial robot manipulators which can replace the human workers in difficult or monotonous jobs, or where a human would otherwise be faced with hazardous conditions. The robot manipulator consists of a robot arm, wrist, and gripper (Fig. 1.2). The robot arm is a serial chain of three rigid segments which are relatively long and provide positioning of the gripper in the workspace. Neighboring segments of a robot arm are connected through a robot joint, which is (Fig. 1.3) either translational (prismatic) or rotational (revolute). The rotational joint has the form of a hinge and limits the motion of two neighbor segments to rotation around the joint axis. The relative position is given by the angle of rotation around the joint axis. In robotics the joint angles are denoted by the Greek letter  $\vartheta$ . In the simplified diagrams the rotational joint is represented by a cylinder. The translational joint restricts the movement of two neighboring segments to translation. The relative position between two segments is measured as a distance. The symbol of the translational joint is a prism, while the distance is denoted by the letter  $d$ . Robot joints are powered by either electric or hydraulic motors. The sensors in the joints are measuring the angle or distance, velocity, and torque.

The robot wrist usually consists of three rotational joints. The task of the robot wrist is to enable the required orientation of the object grasped by the robot gripper. The two- or multi-fingered robot gripper is placed at the robot endpoint. Different tools, to enable drilling, spray painting, or welding devices, can be also attached to the endpoint. Industrial robot manipulators usually allow mobility in six degrees of



**Fig. 1.3** Rotational (left) and translational (right) robot joint



**Fig. 1.4** Degrees of freedom of a rigid body

freedom, meaning that the robotic mechanism has six joints and also six actuators. In this way the robot arm can position an object to an arbitrary place in the robot workspace, while the gripper can rotate the object about all three axes of a rectangular coordinate frame.

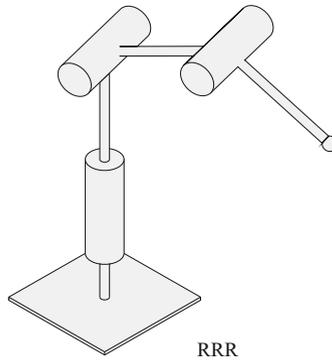
In order to clarify the term degree of freedom, let us first consider a rigid body which usually represents the object manipulated by the industrial robot. The simplest rigid body consists of three mass particles (Fig. 1.4). A single mass particle has three degrees of freedom, described by three displacements along the axes of a rectangular frame. The displacement along a line is called translation. We add another mass particle to the first one in such a way that there is constant distance between them. The second particle is restricted to move on the surface of a sphere surrounding the first particle. Its position on the sphere can be described by two circles reminding us of meridians and latitudes on a globe. The displacement along a circular line is

called rotation. The third mass particle is added in such a way that the distances with respect to the first two particles are kept constant. In this way the third particle may move along the circle, a kind of equator, around the axis determined by the first two particles. A rigid body therefore has six degrees of freedom: three translations and three rotations. The first three degrees of freedom describe the position of the body, while the other three degrees of freedom determine its orientation. The term pose is used to include both position and orientation. It is often said that while the world surrounding us is three-dimensional, the world of a roboticist is six-dimensional.

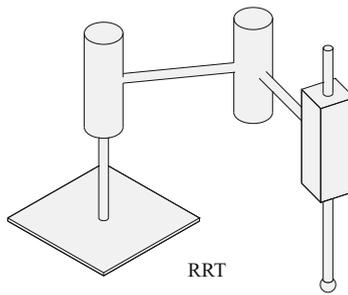
Modern industrial robot manipulators are reprogrammable and multipurpose. In modern industrial production, it is no longer economical to hold large stocks of either materials or products. This is known as: “Just in time” production. As a consequence, it may happen that different types of a certain product find themselves on the same production line during the same day. This problem, which is most inconvenient for fixed automation devices, can be efficiently resolved by using reprogrammable industrial robotic manipulators. Reprogrammable robots allow us to switch from the production of one type of product to another type by touching a push-button. Furthermore, the robot manipulator is a multipurpose mechanism. The robot mechanism is a crude imitation of the human arm. In the same way as we use our arm for both precise and heavy work, we can apply the same robot manipulator to different tasks. This is even more important in view of the economic life span of an industrial robot, which is rather long (12–16 years). It could therefore happen that a robot manipulator acquired for welding purposes, could be reassigned to a pick and place task. Robot arms have another important property, namely, the axes of two neighboring joints are either parallel or perpendicular. As the robot arm has only three degrees of freedom, there exist a limited number of possible structures of robot arms. Among them the most frequently used are anthropomorphic and the so-called SCARA (Selective Compliant Articulated Robot for Assembly) robot arm. Anthropomorphic type of robot arm (Fig. 1.5), has all three joints of the rotational type, and as such it resembles the human arm to the largest extent. The second joint axis is perpendicular to the first one, while the third joint axis is parallel to the second one. The workspace of the anthropomorphic robot arm, encompassing all the points that can be reached by the robot endpoint, has a spherical shape. The SCARA robot arm appeared relatively late in the development of industrial robotics (Fig. 1.6) and is predominantly used for industrial assembly processes. Two of the joints are rotational and one is translational. The axes of all three joints are parallel. The workspace of SCARA robot arm is of the cylindrical type. In the market we can also find three other commercially available structures of the robot arms: cylindrical, Cartesian, and to a lesser extent spherical.

## 1.2 Industrial Robotics

Today’s industry cannot be imagined any longer without industrial robotic manipulators, which can be divided into three different groups. In the first group we classify the industrial robots which have the role of master in a robot cell. A robot cell usually



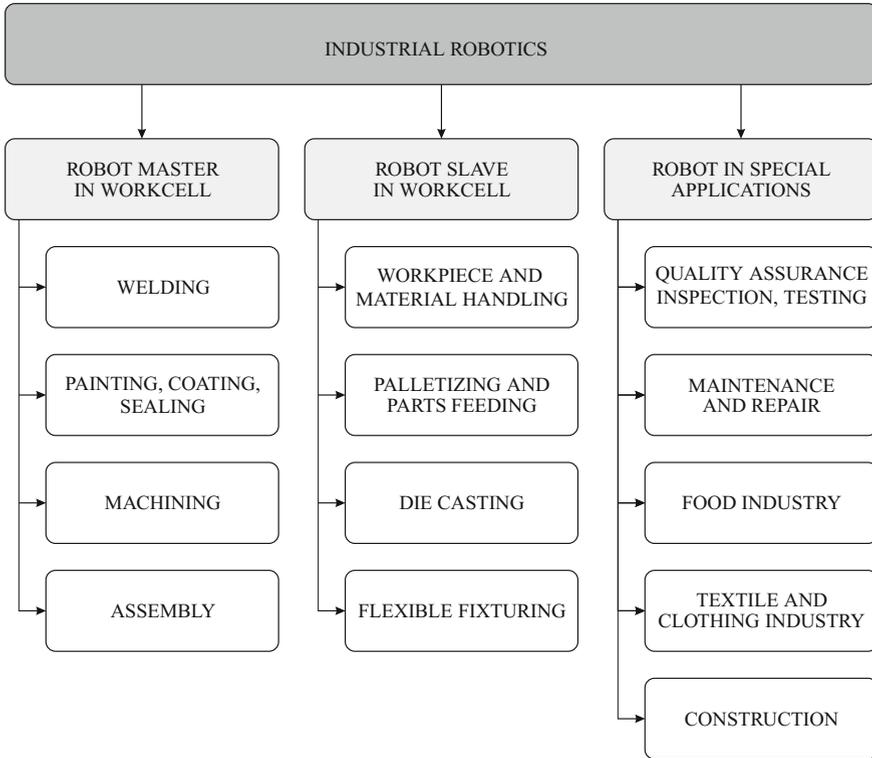
**Fig. 1.5** Antropomorphic robot arm



**Fig. 1.6** SCARA robot arm

compromises one or more robots, workstations, storage buffers, transport systems and numerically controlled machines. In the second group there are the robots which are slaves within the robot cell. In the third group we include the industrial robots which are used in special applications (Fig. 1.7).

Robot masters in a robot cell, can be found in the following production processes: welding, painting, coating, and sealing, machining, and assembly. Robot welding (spot, arc, laser) represents the most frequent robot applications. It is characterized by speed, precision, and accuracy. Robot welding is specially economic when performed in three shifts. Today we encounter the largest number of welding robots in the car industry. There, the ratio of human workers and robots is 6:1. Industrial robots are often used in aggressive or dangerous environments, such as spray painting. Robotic spray painting represents a saving of material together with a higher quality of painted surfaces. Where toxic environment exist, the social motivation for introduction of robots can outweigh economic factors. In machining applications the robot typically holds either a workpiece or a powered spindle and performs drilling, grinding, deburring or other similar applications. Robot manipulators are increasingly entering the area of industrial assembly, where component parts are assembled into a functional systems. The electronic and electromechanical industries represents



**Fig. 1.7** Classification of industrial robots

an important area for the application of assembly robots. There are also attractive assembly operations in the automotive industry, where one robot dispenses adhesive on the windshield glass, while another robot holds the windshield and inserts it into the opening on the vehicle body.

The robot plays the role of a slave in the following industrial applications: workpiece and material handling, palletizing and parts feeding, die casting, and flexible fixturing. In this situation the role of a master can be given to a numerically controlled machine in the robot cell. Pick and place robots represent the most common use of robots in material handling, where tasks are often tedious or repetitive and potentially hazardous (e.g. press loading). Often the industrial robots are used in the tasks when they execute point to point movements. Such examples are encountered in palletizing i.e. arranging of workpieces or products for the purpose of packaging or handing them over to a machine. Robot palletizing is especially appropriate and welcome when heavy objects are considered (e.g. barrels in a brewery). Die casting operations are hot, dirty, and hazardous, providing an unpleasant environment for human workers. With robot handling, the die cast parts are precisely oriented in the die casting machine. The effectiveness of a robot cell can be upgraded by

using of flexible fixturing systems. The flexibility of a robot cell is achieved via servodriven programmable positioners, allowing the manufacturing process to be performed faster and more dexterously.

Special applications of the industrial robots are the following: quality assurance, inspection, and testing, maintenance and repair, robots in food, textile and clothing industry, and in construction. Quality assurance, inspection, and testing are often applied in the electronic industry, where electric parameters (e.g. voltage, current, resistance) are tested during assembly of electronic circuits. In this situation the robot performs the necessary measurements on the object (dimensional, electric), while grasping and placing it into a new position. In robot maintenance and repair teleoperated and autonomous robots are used for variety of applications in nuclear industry, highways, railways, power lines maintenance, and aircraft servicing. Robots are also entering the food industry, where in addition to handling and packaging applications in food processing, they are used for the tasks such as food preparation or even decorating chocolates. The textile and clothing industry presents unique problems because of the limp nature of the workpieces, making handling of textiles or similar materials extremely complicated. Many different types of construction robots have been developed all over the world, however very few have been commercialized.

The key challenges of the present-day robotics are human-robot interaction and human-robot collaboration. The development of the so-called soft robotics enables humans and robots to interact and collaborate in industrial environments, in service and everyday settings. When developing collaborative robots, or shortly co-bots, the safety of human-robot interaction must be ensured. Analysis of human injuries caused by blunt or sharp tool impacts was therefore necessary as the first step in collaborative robots research. Based on numerous studies of human-robot collisions, the safe robot velocities were determined for given robot inertial properties. Safe human-robot interaction is further guaranteed by novel control schemes which measure the torque in each robot joint, detecting the slightest contacts between the robot and the human operator and instantly stopping the robot. The prerequisite for the efficient torque control is an extremely detailed model of the dynamics of the robot. To make the robot manipulator compliant, when in contact with human operator, a biologically inspired approach is also used. Storing the energy in the spring elements in the robot arm joints makes the motion control efficient and natural. Complex co-bots, often applied as multi-arm robot systems, cannot be programmed in the same way as ordinary industrial robot manipulators. Cognitive robotics approaches based on artificial intelligence techniques must be introduced, such as imitation learning, learning from demonstrations, reinforcement learning, or learning from rewards. In this way co-bots are able to perform tasks in unknown and unstructured environments. Special attention must also be devoted to robot hands. In collaborating with human operator, the robot hand must be humanoid in order to be able to operate tools and equipment designed for the human hand. Also, the robot hand must measure the forces exerted to provide a gentle grip. The today's industrial robots are for safety reasons still working behind the fences. Fenceless industrial soft robotics has the potential to open novel unforeseen applications, leading to more flexible and cost-effective automation.