ROBOTICS (Introduction)

The term robot was first introduced by the Czech playwright Karel Čapek in his 1920 play Rossum's Universal Robots, the word robota being the Czech word for worker. Since then the term has been applied to a great variety of mechanical devices, such as teleoperators, underwater vehicles, autonomous cars, drones, etc.

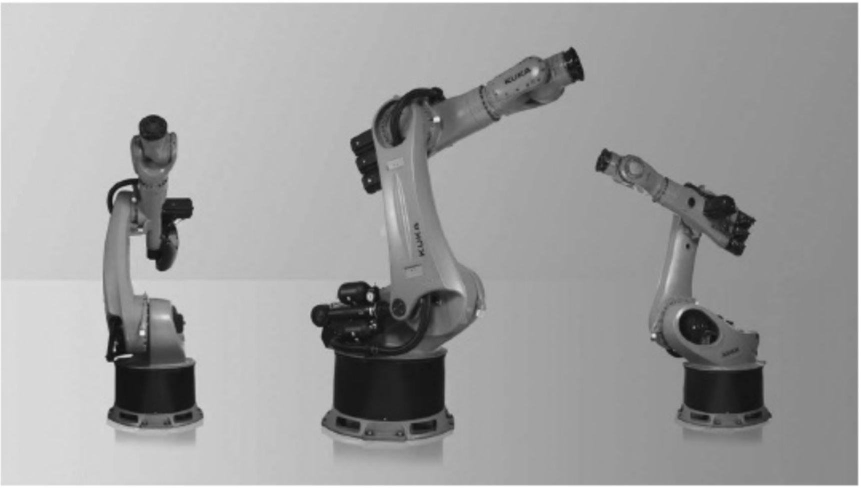

Figure 1.1 A six-axis industrial manipulator, the KUKA 500 FORTEC robot. (Photo courtesy of KUKA Robotics.)

An official definition of such a robot comes from the Robot Institute of America (RIA): A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

ROBOTICS (Introduction)

Classification of Robotic Manipulators Robot manipulators can be classified by several criteria, such as their power source, meaning the way in which the joints are actuated; their geometry, or kinematic structure; their method of control; and their intended application area.

Power Source Most robots are either electrically, hydraulically, or pneumatically powered. Hydraulic actuators are unrivaled in their speed of response and torque producing capability.

Nonservo robots. These robots are essentially open-loop devices whose movements are limited to predetermined mechanical stops, and they are useful primarily for materials transfer.

Servo robots use closed-loop computer control to determine their motion and are thus capable of being truly multifunctional, reprogrammable devices..

Servo point-to-point robot. A point-to-point robot can be taught a discrete set of points but there is no control of the path of the end effector in between taught points. Such robots are usually taught a series of points with a teach pendant. The points are then stored and played back. Point-to-point robots are limited in their range of applications.

Servo continuous path robots, on the other hand, the entire path of the end effector can be controlled. For example, the robot end effector can be taught to follow a straight line between two points or even to follow a contour such as a welding seam. In addition, the velocity and/or acceleration of the end effector can often be controlled.

Most industrial manipulators at the present time have six or fewer DOF. These manipulators are usually classified kinematically on the basis of the first three joints of the arm, with the wrist being described separately. The majority of these manipulators fall into one of five geometric types: articulated (RRR), spherical (RRP), SCARA (RRP), cylindrical (RPP), or Cartesian (PPP)..

ROBOTICS (Introduction)

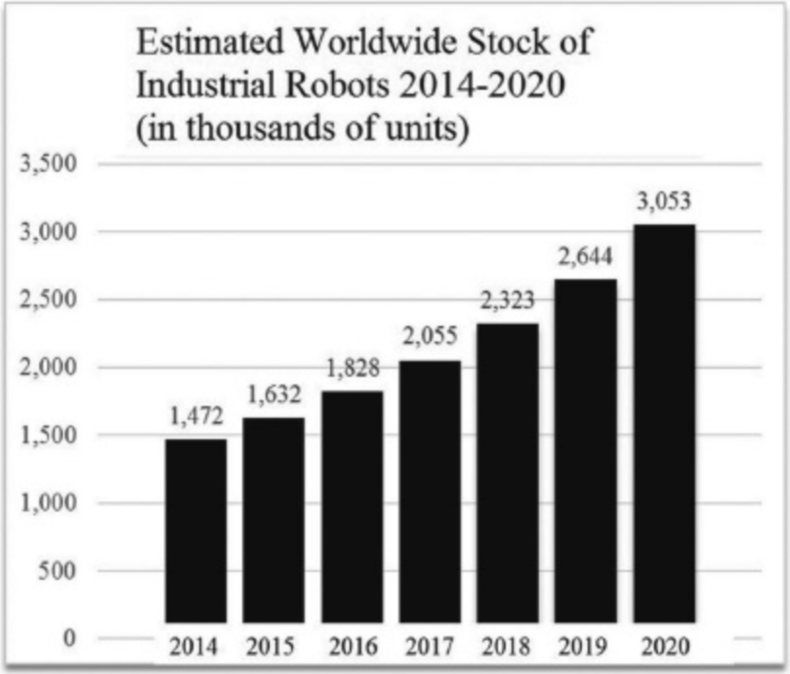

Figure 1.2 Estimated number of industrial robots worldwide 2014–2020. The industrial robot market has been growing around 14% per year. (Source: International Federation of Robotics 2018.)

ROBOTICS (Introduction)

Robot manipulators are composed of links connected by joints to form a kinematic chain. Joints are typically rotary (revolute) or linear (prismatic). A revolute joint is like a hinge and allows relative rotation between two links. A prismatic joint allows a linear relative motion between two links. We denote revolute joints by R and prismatic joints by P, and draw them as shown in Figure 1.4. For example, a three-link arm with three revolute joints will be referred to as an RRR arm.

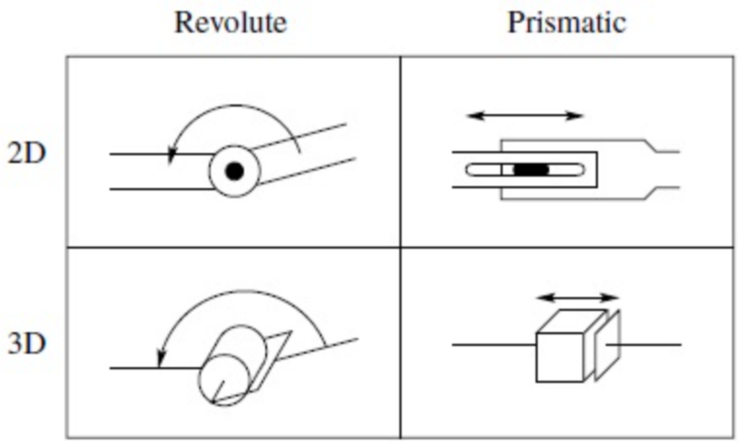

Figure 1.4 Symbolic representation of robot joints. Each joint allows a single degree of freedom of motion between adjacent links of the manipulator. The revolute joint (shown in 2D and 3D on the left) produces a relative rotation between adjacent links. The prismatic joint (shown in 2D and 3D on the right) produces a linear or telescoping motion between adjacent links.

ROBOTICS (Introduction)

Figure 1.5 The Kinova® Gen3 Ultra lightweight arm, a 7-degree-of-freedom redundant manipulator. (Photo courtesy of Kinova, Inc.)

Each joint represents the interconnection between two links. We denote the axis of rotation of a revolute joint, or the axis along which a prismatic joint translates by z_i if the joint is the interconnection of links i and $i + 1$. The joint variables, denoted by θ for a revolute joint and d for the prismatic joint, represent the relative displacement between adjacent links. We will make this precise in Chapter 3.

Robotics (Introduction)

A robot manipulator should be viewed as more than just a series of mechanical linkages. The mechanical arm is just one component in an overall robotic system, illustrated in Figure 1.6, which consists of the arm, external power source, end-of-arm tooling, external and internal sensors, computer interface, and control computer. Even the programmed software should be considered as an integral part of the overall system, since the manner in which the robot is programmed and controlled can have a major impact on its performance and subsequent range of applications.

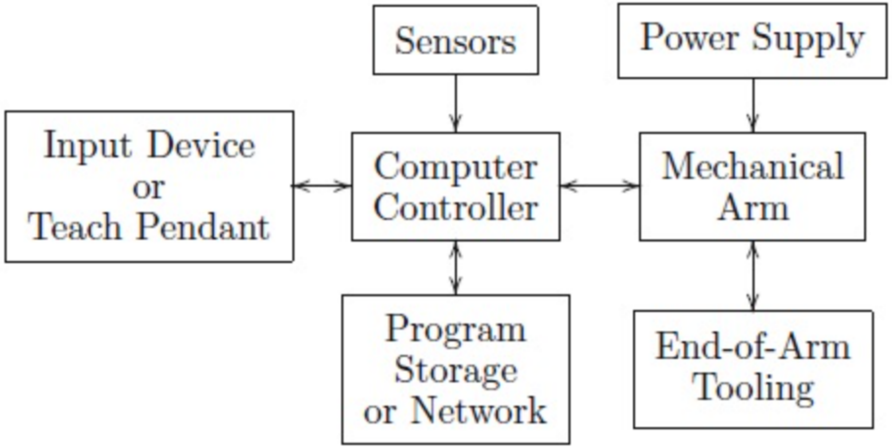

Figure 1.6 The integration of a mechanical arm, sensing, computation, user interface and tooling forms a complex robotic system. Many modern robotic systems have integrated computer vision, force/torque sensing, and advanced programming and user interface features.

ROBOTICS (Introduction)

Accuracy of a manipulator is a measure of how close the manipulator can come to a given point within its workspace.

Repeatability is a measure of how close a manipulator can return to a previously taught point. The primary method of sensing positioning errors is with position encoders located at the joints, either on the shaft of the motor that actuates the joint or on the joint itself. There is typically no direct measurement of the end-effector position and orientation.

Controller resolution means the smallest increment of motion that the controller can sense. The resolution is computed as the total distance traveled divided by 2n, where n is the number of bits of encoder accuracy.

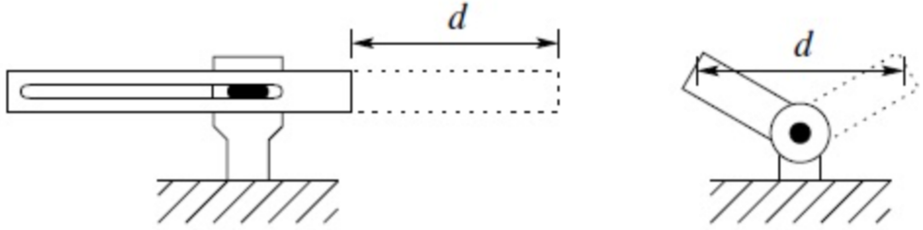

Figure 1.7 Linear vs. rotational link motion showing that a smaller revolute joint can cover the same distance *d* as a larger prismatic joint. The tip of a prismatic link can cover a distance equal to the length of the link. The tip of a rotational link of length *a*, by contrast, can cover a distance of 2*a* by rotating 180 degrees.

ROBOTICS (Introduction)

The joints in the kinematic chain between the arm and end effector are referred to as the wrist. The wrist joints are nearly always all revolute. It is increasingly common to design manipulators with spherical wrists, by which we mean wrists whose three joint axes intersect at a common point, known as the wrist center point. Such a spherical wrist is shown in Figure 1.8.

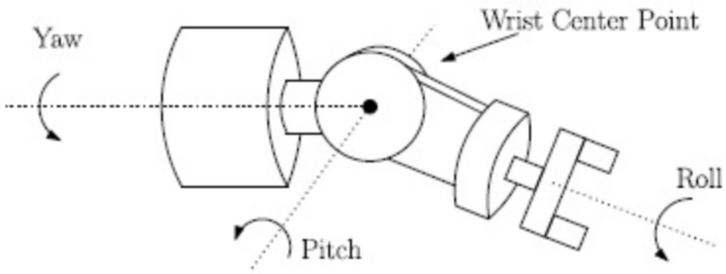

Figure 1.8 The spherical wrist. The axes of rotation of the spherical wrist are typically denoted roll, pitch, and yaw and intersect at a point called the wrist center point.

ROBOTICS (Introduction)

The arm and wrist assemblies of a robot are used primarily for positioning the hand, end effector, and any tool it may carry. It is the end effector or tool that actually performs the task. The simplest type of end effector is a gripper, such as shown in Figure 1.9, which is usually capable of only two actions, opening and closing. While this is adequate for materials transfer, some parts handling, or gripping simple tools, it is not adequate for other tasks such as welding, assembly, grinding, etc.

Figure 1.9 A two-finger gripper. (Photo courtesy of Robotiq, Inc.)

ROBOTICS (Introduction)

A great deal of research is therefore devoted to the design of special purpose end effectors as well as of tools that can be rapidly changed as the task dictates. Since we are concerned with the analysis and control of the manipulator itself and not in the particular application or end effector, we will not discuss the design of end effectors or the study of grasping and manipulation. There is also much research on the development of anthropomorphic hands such as that shown in Figure 1.10.

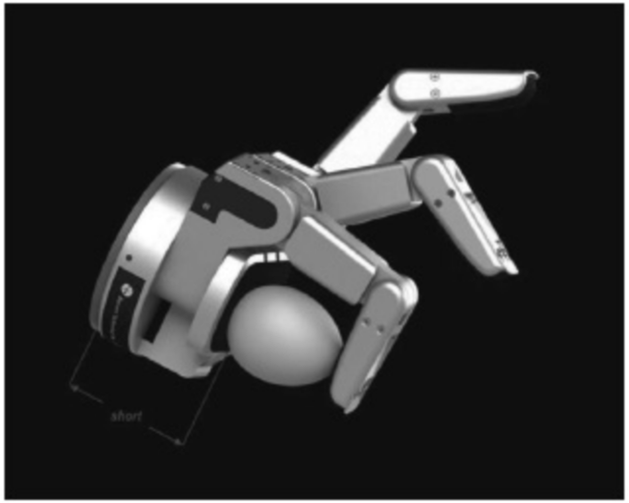

Figure 1.10 Anthropomorphic hand developed by Barrett Technologies. Such grippers allow for more dexterity and the ability to manipulate objects of various sizes and geometries. (Photo courtesy of Barrett Technologies.)

We give below some of the important milestones in the history of modern robotics.

- 1947 — The first servoed electric powered teleoperator is developed.
- 1948 — A teleoperator is developed incorporating force feedback.
- 1949 — Research on numerically controlled milling machine is initiated.
- 1954 — George Devol designs the first programmable robot
- 1956 — Joseph Engelberger, a Columbia University physics student, buys the rights to Devol's robot and founds the Unimation Company.
- 1961 — The first Unimate robot is installed in a Trenton, New Jersey plant of General Motors to tend a die casting machine.
- 1961 — The first robot incorporating force feedback is developed.
- 1963 — The first robot vision system is developed.
- 1971 — The Stanford Arm is developed at Stanford University.
- 1973 — The first robot programming language (WAVE) is developed at Stanford.
- 1974 — Cincinnati Milacron introduced the T^3 robot with computer control.
- 1975 — Unimation Inc. registers its first financial profit.
- 1976 — The Remote Center Compliance (RCC) device for part insertion in assembly is developed at Draper Labs in Boston.
- 1976 — Robot arms are used on the Viking I and II space probes and land on Mars.
- 1978 — Unimation introduces the PUMA robot, based on designs from a General Motors study.
- 1979 — The SCARA robot design is introduced in Japan.
- 1981 — The first direct-drive robot is developed at Carnegie-Mellon University.

- 1982 — Fanuc of Japan and General Motors form GM Fanuc to market robots in North America.
- 1983 — Adept Technology is founded and successfully markets the direct-drive robot.
- 1986 — The underwater robot, Jason, of the Woods Hole Oceanographic Institute, explores the wreck of the Titanic, found a year earlier by Dr. Robert Barnard.
- 1988 — Stäubli Group purchases Unimation from Westinghouse.
- 1988 — The IEEE Robotics and Automation Society is formed.
- 1993 — The experimental robot, ROTEX, of the German Aerospace Agency (DLR) was flown aboard the space shuttle Columbia and performed a variety of tasks under both teleoperated and sensor-based offline programmed modes.
- 1996 — Honda unveils its Humanoid robot; a project begun in secret in 1986.
- 1997 — The first robot soccer competition, RoboCup-97, is held in Nagoya, Japan and draws 40 teams from around the world.
- 1997 — The Sojourner mobile robot travels to Mars aboard NASA's Mars PathFinder mission.
- 2001 — Sony begins to mass produce the first household robot, a robot dog named Aibo.
- 2001 — The Space Station Remote Manipulation System (SSRMS) is launched in space on board the space shuttle Endeavor to facilitate continued construction of the space station.
- 2001 — The first telesurgery is performed when surgeons in New York perform a laparoscopic gall bladder removal on a woman in Strasbourg, France.

•2001 — Robots are used to search for victims at the World Trade Center site after the September 11th tragedy.
•2002 — Honda's Humanoid Robot ASIMO rings the opening bell at the New York Stock Exchange on February 15th.
•2004 — The Mars rovers Spirit and Opportunity both landed on the surface of Mars in January of this year. Both rovers far outlived their planned missions of 90 Martian days. Spirit was active until 2010 and Opportunity stayed active until 2018, and holds the record for having driven farther than any off-Earth vehicle in history.
•2005 — ROKVISS (Robotic Component Verification on board the International Space Station), the experimental teleoperated arm built by the German Aerospace Center (DLR), undergoes its first tests in space.
•2005 — Boston Dynamics releases the quadrupedal robot Big Dog.

HOMEWORK #1 Bring this list up to date by summarizing the most significant robotic accomplishments of your lifetime .