management. The three levels of automation one may refer to are: rigid automation, programmable automation, and flexible automation.

Rigid automation deals with a factory context oriented to the mass manufacturing of products of the same type. The need to manufacture large numbers of parts with high productivity and quality standards demands the use of fixed operational sequences to be executed on the workpiece by special purpose machines.

Programmable automation deals with a factory context oriented to the manufacturing of low-to-medium batches of products of different types. A programmable automated system allows easily changing the sequence of operations to be executed on the workpieces in order to vary the range of products. The machines employed are more versatile and are capable to manufacture different objects belonging to the same group technology. The majority of the products available on the market today are manufactured by programmable automated systems.

Flexible automation represents the evolution of programmable automation. Its goal is to allow manufacturing of variable batches of different products by minimizing the time lost for reprogramming the sequence of operations and the machines employed to pass from one batch to the next. The realization of a flexible manufacturing system demands a strong integration of computer technology with industrial technology.

The *industrial robot* is a machine with significant characteristics of versatility and flexibility. According to the widely accepted definition of the Robot Institute of America, *a robot is a reprogrammable multifunctional manipulator designed to move materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks*. Such a definition, dating to 1980, reflects the current status of robotics technology.

By virtue of its programmability, the industrial robot is a typical component of programmable automated systems. Nonetheless, robots can be entrusted with tasks both in rigid automated systems and in flexible automated systems. An industrial robot is constituted by:

- A mechanical structure or *manipulator* that consists of a sequence of rigid bodies (*links*) connected by means of articulations (*joints*); a manipulator is characterized by an *arm* that ensures mobility, a *wrist* that confers dexterity, and an *end effector* that performs the task required of the robot.
- *Actuators* that set the manipulator in motion through actuation of the joints; the motors employed are typically electric and hydraulic, and occasionally pneumatic.
- *Sensors* that measure the status of the manipulator (proprioceptive sensors) and, if necessary, the status of the environment (heteroceptive sensors).
- A *control system* (computer) that enables control and supervision of manipulator motion.

The essential feature that differentiates an industrial robot from a numerically controlled machine tool is its enhanced versatility; this is endowed by the manipulator's

end effector, which can be many a tool of different type, as well as by the large workspace compared to manipulator encumbrance.

Industrial robots present three fundamental capacities that make them useful for a manufacturing process: *material handling*, *manipulation*, and *measurement*.

In a manufacturing process, each object has to be transferred from one location of the factory to another in order to be stored, manufactured, assembled, and packed. During transfer, the physical characteristics of the object do not undergo any alteration. The robot's capacity to pick up an object, move it in space on predefined paths and release it makes the robot itself an ideal candidate for material handling operations. Typical applications include:

- palletizing (placing objects on a pallet in an ordered way),
- warehouse loading and unloading,
- mill and machine tool loading and unloading,
- part sorting,
- packaging.

Manufacturing consists of transforming objects from raw material into finished products; during this process, the part either changes its own physical characteristics as a result of machining or loses its identity as a result of an assembly of more parts. The robot's capacity to manipulate both objects and tools make it suitable to be employed for manufacturing. Typical applications include:

- arc and spot welding,
- spray painting,
- milling and drilling,
- gluing and sealing,
- laser and water jet cutting,
- deburring and grinding,
- assembly of mechanical and electrical groups,
- assembly of electronic boards,
- screwing,
- wiring.

Besides material handling and manipulation, in a manufacturing process it is necessary to perform measurements to test product quality. The robot's capacity to explore the three-dimensional space together with the availability of measurements on the manipulator's status allow using a robot as a measuring device. Typical applications include:

Object inspection
Contour finding
Detection of manufacturing imperfections