Recent Trends in Robotics

BHASKAR DASGUPTA
Department of Mechanical Engineering,
Indian Institute of Science, Bangalore - 560 012.

Out of the shrouds of the myth of imagination, the Science of Robotics took its first faltering steps into the real world half a century back. Its infancy being over, the young discipline is now extending its arms towards diverse goals - to new applications, to new environments, to meet new demands of a new society - “Still achieving, still pursuing” in its endless quest for PERFECTION.

Robotics is a branch of applied science, the popular conception of which came not from science, but from drama, fiction and cinema. The word “robot” was first used in 1921 by Czech playwright Karel Capek in his play “Rossum’s Universal Robots” where robots were machines resembling human beings except that they were exceptionally hardworking. The word “Robotics” which means the study of robots, was later coined in 1942 by science fiction writer Isaac Asimov in his story “Runaround” where he put forward three “laws” of robotics. Science fiction writers including Asimov and film-makers used the concept of robots widely and projected robots as human-like mechanical “beings” with tremendous physical and intellectual capabilities, compared to which even the most sophisticated robots of today will look very primitive.

This budding of the new science in the cradles of arts had two-fold results. On one side, robotics got a natural terminology straight from
human anatomy with words like arm, shoulder, elbow, wrist, hand, finger, leg, knee, ankle, foot etc and an ideal system, namely the human body, to get new ideas and to evaluate the performance of existing system. On the other hand, a myth was created in the minds of laymen regarding human-like machines called robots, the sophistication of which is quite phenomenal. To many people, the word “robot” gives rise to a mental picture of a metallic human of tremendous strength and a picture of an actual robot would be rather disappointing. An actual industrial robot can, of course, look similar to a human arm, in basic mechanical architecture. For example, the motion capabilities of a six degrees of freedom PUMA robot can be explained in analogy with movements at shoulder, elbow and wrist of a human arm. Many other robots, however, depart from this analogy to different extents depending on their architecture, though they perform the same jobs as PUMA. The four principal components of a robot, namely the manipulator, the controller, the sensors and the actuators roughly resemble in function (though not in appearance) the human arm, brain, sense organs and muscles.

A standard definition (given by Robot Institute of America) describes a robot as a “reprogrammable multifunctional manipulator”. In that perspective, hard automation systems and numerically controlled (NC) machines do not fall within the scope of robotics. Teleoperators or telerobots also fall near the border line. Though programmable machines existed even in the 19th century, the science of robotics came into being in the last 50 years through the epoch-making developments of first telerobot to handle radioactive material (world war II), first servoed electric-powered teleoperators (1947–48), NC machines (1952), first reprogrammable robot (1954) and the installation of the first robot (1961). By the 1970’s, robotics emerged as an independent field of study. Nowadays, robots are used for material handling, welding, spray-painting, teleoperations (in inaccessible and/or
hazardous places), assembly, machining etc.

With this introduction to the field of robotics, let us have a look at the recent trends in robotic research and application, which can be described under the following broad headings.

**Redundant Robots:** Six degrees of freedom are, in principle, enough to manipulate objects in space with three possible independent translations and three independent rotations. But, with a given architecture of a robot arm and a given working environment, restrictions of workspace, dexterity and obstacles call for additional degree(s) of freedom. In such cases, as a human being uses additional freedoms of the body to supplement the capabilities of the arm for enhancing the reach, manipulate objects comfortably and reach below the table or around the corner objects, additional degrees of freedom can be provided in the robot arm with extra joints and links. Such robots are called redundant robots (because they use more inputs than necessary) and are used for the purposes of workspace enhancement and avoidance of singularities and obstacles. With a redundant robot, a particular point can be reached in infinite number of ways — to choose one of those infinite ways is the problem of redundancy resolution, which is solved by optimizing the performance.

**Space Robots:** Robots in space applications are light, can handle greater masses and have a special characteristic that, unlike robots on earth, their frames are not fixed, rather they float with the rest of the robot, together with the space vehicle.

**Flexible Robots:** Truly speaking, all solid bodies are flexible. Conventional modelling of robot manipulators needs to consider the links of a robot as rigid, for which the deflections have to be negligible from the viewpoint of positional accuracy. Consequently, the links are to be designed stronger than necessary and heavy. But, from a physical point of view, it is not necessary and we should not mind the links being flexible as long as they are within elastic limits and we know
their behaviour. So, the recent interest has been to work with flexible robots and to take advantage of their light weight by incorporating their flexibility into the mathematical model which, of course, complicates the dynamics of the system — a price to be paid for the advantage gained.

**Parallel-actuated Robots and Closed-loop Robots:** The traditional serial chain robots, due to their cantilever structure, have less load carrying capacity. Actuations off the base aggravate this problem and make the robot bulky. Consequently, the serial robots tend to bend at high load and vibrate at high speed. Though they possess a large workspace, the positioning capability is rather poor. So, where high load carrying capacity and precise positioning is of prime concern, an alternative is provided by parallel-actuated and closed-loop robots which have attracted tremendous research interest in the last 15 years. As a human being uses both arms to handle a heavy load, three fingers in parallel for doing a precise work like writing and as animal body is supported on four legs with provision of in-parallel actuation at the leg joints, robot manipulators also can be designed with the end-effector (hand) connected to the frame by parallel chains of joints and links having the actuations distributed among the various chains or legs. The most celebrated among the parallel manipulators is the six-degrees-of-freedom parallel manipulator called the Stewart platform which has its end-effector connected to the ground by six extensible legs having ball-socket joints at the ends, the extensions of the legs being done by six linear actuators. Parallel robots, in general, provide high structural rigidity and load carrying capacity, good positioning capabilities and have less vibration. But, they generally have restricted workspaces and their kinematics and dynamics is quite complicated to study and analyse. Typical applications of parallel robots include applications where high load capacity and precise positioning are required, use as an assembly workstation, dexterous wrist and micromanipulators. The
application of the concept of parallel actuation has uses in cooperating robots and in multi-fingered gripping and manipulation.

**Walking Robots:** While manipulation robots manipulate objects by utilizing the freedom available at the joints, mobile robots can carry objects to greater distances by body movement. In ordinary life, we use trains, automobiles and animals for conveyance. Similarly, in robotics, we have tracked, wheeled and legged vehicles. Though all of these have their own applications, walking machines have enjoyed the maximum research interest due to their versatility over terrain irregularities and greater mobility, and work is mostly focused on machines walking on two to six legs. Till now, most of these walking machines have succeeded mostly in laboratory conditions and have achieved little breakthrough on completely unstructured ground, but the attempts in this direction promise a high potential. Recently BARC has developed a walking machine with six legs (presented in National Convention on Industrial Problems in Machines and Mechanisms 1994) which moves forward and can take turns also, but the walking speed is quite low. A challenging field of research is biped locomotion which gives rise to a problem of stability, which is evident as equilibrium of a body with less than three supports is precarious. The ease of biped locomotion in human beings can be attributed to their erect body structure, the extent and nature of the surface of the foot and an extremely smart nervous system — conditions simulating which in machines is a really challenging task.

**Model-based Control:** The traditional control strategy of robot manipulators is completely error driven and shows poor performance at high-speeds, when the high dynamic forces act as disturbances. The current trend is towards model-based control, where the dynamic forces are incorporated in the control strategy as feedforward gains and feedback compensations along with the servo-controller which is required only to take care of external noise and other factors not included in the dynamic model of the robot. As is expected, the model-based control
scheme exhibits better performance, but demands higher computational load in real time. A particular area of model-based control is adaptive control, which is useful when the dynamic parameters of the robot are not well-known a priori. The controller adapts itself during execution of tasks and improves the values of the dynamic parameters.

**Force Control:** Conventional control schemes primarily concentrate on position control. But certain tasks (e.g., cleaning a window pane) require the maintenance of some required contact forces. Current trend is to control the force in such directions (in such applications) and position in other directions. The use of compliance (flexibility) also is getting popular in control. In applications like insertion of a peg into a hole, if the positional accuracy is poor, the forces stemming from such errors tend to correct the position, if some compliance is provided at the wrist.

**Robot Intelligence and Vision:** Intelligence, as pertaining to human beings, is a very subtle and profound quality which cannot be learnt or taught (though can be enhanced in scope and application) and cannot be described in terms of logic and knowledge alone. Again, knowledge is much more than a collection of pieces of information. As the so-called machine intelligence of the present time basically stems from the information and logic coded in computer, we cannot expect true ‘intelligence’ in a robot right now in the sense of the robot having true ‘understanding’. Still, the intelligent robots, as they are called, constitute an extremely popular topic in robotics, because they can perform various tasks in an apparently intelligent manner. For example, machine intelligence can be applied for path planning and obstacle avoidance by maintaining (and updating) a complete CAD model of the working environment such that the robot navigates through obstacles without collision. As sight, sound and touch assist human intelligence so far as the knowledge of the external world is concerned, robots also are equipped with sensors (optical, ultrasonic, tactile) for
feedback. When a robot has to work in a poorly structured or unstructured environment (the environment not being completely known a priori), the robot intelligence heavily relies on ‘vision’, which is the process of extracting, characterizing and interpreting information from two-dimensional images of the three-dimensional world. In the whole processing of an image, the interpretation of a scene is the most difficult task and requires highest level of intelligence. The maturity of this technique is expected to provide tremendous decision-making capabilities to the robots.

The dream of perfection for the science of robotics is a system equipped with high-performance sensors and stereo vision, such that it can work in unstructured environment where changes in scenario may be rapid and unexpected. In addition, certain degree of fault-tolerance is desirable with decision-making capabilities such that it can perform tasks assigned to it as long as they are physically possible.