

Fig. 1.9 A set of related topics in robotics with a motion-centric theme.

1.6 Issues in Robotics

Robotics, or the study of robots, is an engineering discipline. Functionally, a robot is a physical agent which is capable of executing motion for the achievement of tasks. A robot's degree of autonomy depends on its ability to perform the ordered sequence of perception, decision-making and action.

As we know, a robot's dynamics in motion execution is dictated by mechanical energy consumption in connection with kinematic constraints imposed by the robot's mechanisms. Literally, the definitions of kinematics and dynamics are as follows:

Definition 1.9 Kinematics is the study of motion without consideration of force and torque, while dynamics is the study of motion in relation to force and torque.

Therefore, the unifying concept in robotics is *motion*, being a visible form of action. As illustrated in Fig. 1.9, the major issues in robotics will logically include:

1.6.1 Mechanism and Kinematics

From a mechanical point of view, a mechanism is a set of linkages without an actuator. The purpose of a mechanism is to impose kinematic constraints on the types of motion the mechanism can deliver at a particular point. By default, this particular point is at the tip of an end-effector.

In general, a mechanism consists of joints and links. In robotics, a *link*

is a rigid body inside a mechanism, while a *joint* is the point of intersection between any pair of adjacent links. Any changes in the relative geometry among the links will induce a specific type of motion. Therefore, it is important to study the relationship between the motion parameters of the linkages and the motion parameters of a particular point on the mechanism. This study is the object of *robot kinematics*. There are two problems with robot kinematics:

- How do we determine the motion parameters of a particular point on the mechanism from the knowledge of the motion parameters of the linkages? This is commonly called the *forward kinematics* problem.
- How do we determine the motion parameters of the linkages necessary to produce a desired set of motion parameters at a particular point on a mechanism? This is known as the *inverse kinematics* problem.

1.6.2 Actuation Elements and Dynamics

In the mechanical domain, any motion is produced by the conversion of mechanical energy. The study of the relationship between motion parameters and force/torque is the object of *robot dynamics*. This discipline aims at determining the equations of motion imposed by force and torque on a robot's mechanism.

Mechanical energy can be generated either through gravitational force or some other form of energy. Today, the most widely available source of energy is electrical energy. Hence, it is important to study the conversion from electrical energy to mechanical energy. This leads to the study of electric motors, which use the electro-magnetic principle to induce mechanical movement from the interaction of two independent magnetic fields. A magnetic field can be generated by either a permanent magnet or electro-magnet.

Being able to convert electrical energy into mechanical energy is important but not sufficient. We must also be able to modulate the mechanical energy being produced. There are two ways to modulate the final output of mechanical energy. It is common at the output side to use a transmission mechanism which is a combination of reducers, tendons, gears and bearings. It is common at the input side to use a power amplifier to regulate the amount of electrical energy, which is converted into the corresponding mechanical energy.

1.6.3 *Sensing Elements*

From an engineering point of view, any system in a real environment is invariably subject to certain types of noise, uncertainty and disturbance. Therefore, no mathematical description of the input and output relationship is ever exact. Sensing is the only way to obtain the actual output values.

In robotics, sensing elements are used to convert physical quantities such as the motion parameters of actuators into corresponding electrical signals. Output from a sensing element provides feedback on the motion parameters regarding the linkages inside a robot's mechanism.

Besides the sensing of motion parameters, there are two other requirements for sensing: a) the measurement of the interaction force/torque between a robot's end-effector and its environment, and b) the motion parameters of a robot's workpieces and workspace. (This latter will be the object of study when we discuss the robot's visual-perception system).

1.6.4 *Control*

The robot's intrinsic dynamics are described by the relationship between the motion parameters of a robot's end-effector and the forces/torques applied to the robot's mechanism. Since a robot is designed to perform tasks through the execution of motions, the dynamics of a robot must closely (if not exactly) follow the desired dynamics imposed by a task. How to determine the desired dynamics from a given task will be studied under the topic of motion planning.

In general, it is impossible to design a robot which has intrinsic dynamics that meets the intended dynamics of any given task. Therefore, it is desirable to have a mean to alter the robot's intrinsic dynamics externally. In engineering, the discipline of automatic-feedback control is the study of methods and tools for the analysis and synthesis of system dynamics. The beauty of the automatic-control theory is its versatility. You can alter a system's intrinsic dynamics through the insertion of a control element (controller) in a closed-feedback loop so that the system's actual dynamics meet a wide range of specifications, in terms of stability, time responsiveness, and output accuracy.

1.6.5 *Information and Decision-Making*

Today, it would be inconceivable to attempt to build an automatic machine without a brain. The hardware aspect of a machine's brain can be

as simple as a micro-controller, or a microprocessor having a certain level of computational power. The first function of a robot's brain is to perform computational tasks, such as sensory-data processing (including visual perception) and the mathematical computations underlying robot kinematics, robot dynamics, and robot control.

The second function of a robot's brain is to support not only the interaction between the robot and human master, but also the communication between the robot and the outside world. The third and most important function of a robot's brain is to implant computational algorithms of artificial intelligence. One important aspect of a robot's intelligence is the ability to plan tasks, actions and motions without human intervention.

In fact, research on developmental principles for acquiring perceptive, thinking and acting skills is aimed at developing a skill-based approach for the autonomous planning of task, action and motion. This is because associating a sequence of ordered actions/motions with the corresponding results is a skill which can be learned with the help of linguistic processing and programming.

1.6.6 *Visual Perception*

Vision is the most important sensory channel for humans (as well as animals). Without vision, our abilities to act and learn would be tremendously weakened. In a similar manner, vision plays a vital role in any machine which intends to perform autonomous motions, actions, tasks, or even behaviors.

In robotics, the performance of a task implies that a robot's actual dynamics closely follows the dynamics required by the task itself. The actual dynamics of a robot, manifested in the form of visible motions, can be measured in two ways. The first approach is to use sensors to measure the motion parameters of the linkages inside the robot's mechanism. Subsequently, it is possible to use forward kinematics to derive the motion parameters at a particular point (e.g. end-effector) on the mechanism. The second approach is to use artificial vision to measure the motion parameters at a particular point on the robot's mechanism. This ability to provide accurate visual feedback to the control loop of motion execution constitutes the first function of a robot's visual-perception system.

The second important function of a robot's visual perception system is to describe an action in two-dimensional (2-D) image space instead of expressing it in three-dimensional (3-D) task space. This is a crucial step

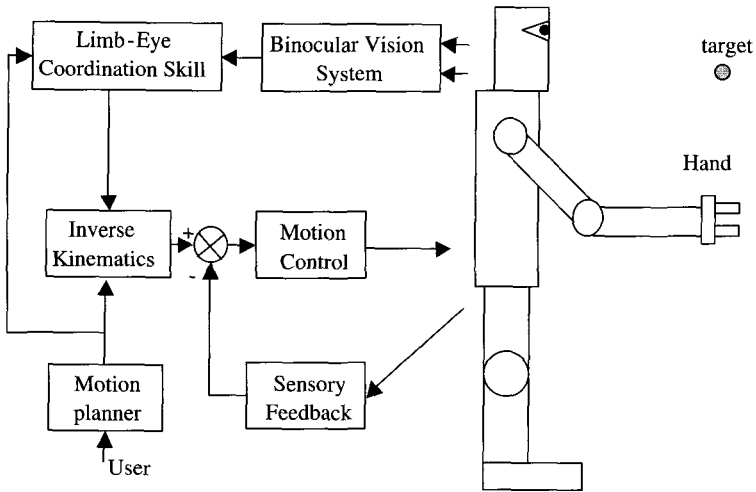


Fig. 1.10 A Framework for Limb-Eye Coordination Behavior.

towards achieving the autonomous execution of a given action.

The third important function of visual perception is to infer the 2-D and/or 3-D geometry of a robot's workpieces and workspace as a necessary step towards the robot's automated planning of an action/task. This is because the automatic generation of an action/task plan requires knowledge of the geometric models of the workspace and workpieces.

The fourth important function of visual perception is to provide visual input to support a robot's learning process.

Finally, if one considers image-based communication/interaction a special skill, it can be regarded as the fifth function of visual perception.

As we know, action is the source of results. With well-developed perception capability, the limb-eye coordination behavior, as illustrated in Fig. 1.10, will be achievable. Of these behaviors, the most impressive ones will be: a) vision-guided manipulation (i.e. hand-eye coordination), b) vision-guided positioning (head-eye coordination), and c) vision-guided locomotion (leg-eye coordination). Chapter 9 will not only cover well-known, pure engineering principles, but also report the latest findings on human-like, engineering approaches to limb-eye coordination behavior.