1.5 Impact of Humanoid Robots

The enhanced locomotive ability of humanoid robots will increase the range of the manipulative function. With the tight integration of perceptive ability, a humanoid robot will gain a certain level of autonomy by interacting with human masters or executing tasks intelligently. The inclusion of cognitive ability will make a humanoid robot a physical agent, capable of self-developing its mental and physical capabilities through real-time interaction with the environment and human masters. There is no doubt that the emergence of humanoid robots will have great impact on many aspects of our modern society.

1.5.1 *Industry*

The enhanced and human-like locomotive ability of the humanoid robot makes it possible to deploy humanoid robots to places where humans are still working like machines. Within the manufacturing industry itself, it is foreseeable that the emergence of the humanoid robot will certainly automate more tasks, such as: maintenance, diagnostics, security etc. We can even imagine that an un-manned factory may become a reality one day. It is clear as well, that the humanoid robot will also benefit other industries. For example, construction of buildings or houses can be considered as an assembly process, which could automatically be completed by specialized teams of humanoid robots under the supervision of human masters. In the healthcare industry, humanoid robots could provide great service in the rehabilitation of patients. Additionally, humanoid robots could be of assistance in hospitals for certain tasks (e.g. precision surgery).

1.5.2 *Society*

Up until today, the greatest consumer product has undoubtedly been the automobile. It provides us with unprecedented mobility, increases our sense of social status, and offers us high-quality, in-vehicle entertainment experiences among other things. Without the automobile, there would be no efficient transportation. Now, the question is: What will be the next great consumer product? If we look at the evolution of the computer as a consumer product, we may discover the following trends:

- The microprocessor is becoming smaller, while computational power is increasing.

- The microprocessor is consuming less electrical power, despite the increased computational power.
- The computer has more functions and better performance while the price is constantly decreasing.
- The computer is constantly improving its cognitive abilities: soft computing (i.e. computation with words rather than digital logic), speech recognition, auditory communication, visual communication, visual perception etc.
- The computer has the ability to express inner emotional states through visible motions (e.g. facial expressions).

The evolution of the computer coincides with the evolution of the robot, which is characterized by the following clear trends:

- The robot's arm is becoming smaller, yet it has increased manipulative ability.
- The robot's hand is becoming more compact, yet it has increased dexterity and sensing ability.
- The robot has a head, which may influence the design of future computer's monitor, and provide the means for facial expressions and perceptive sensory input and output.
- The robot has legs to perform human-like, biped walking.
- The robot is becoming intelligent. The incorporation of demanding computational power and cognitive abilities enables the robot to perform real-time interaction with its environment and humans.
- The robot is becoming the perfect embodiment of an artificial body with artificial intelligence.

The parallel development of the computer and robot industries, each of which has its own group of manufacturers with sound and profitable track records, will contribute to the emergence of the humanoid robot as the next great consumer product. Undoubtedly, this will bring new benefits to consumers, such as:

- *Robot-assisted Entertainment*:
  Computerized games are very popular. These are basically pre-programmed interactions between users and artificial creatures in a virtual world. With the humanoid robot, or an animal-like robot, computerized games will take on a new dimension: a pre-programmed interaction with artificial creatures in real space. Moreover, with the humanoid robot, certain animations or tours could also be automated

in places, such as museums, hotels, shopping centers, theme parks, film studios etc.

- *Robot-assisted Healthcare at Home*:
  Healthcare is expensive. One effective way to lower the cost is to increase the accessibility of healthcare services. This would be possible, if humanoid robot technology advanced to the stage where we could deploy humanoid robots to homes, both locally and in remote areas. By simply activating the appropriate pre-coded programs, a humanoid robot could instantaneously be configured as an "expert" in the necessary medical field. (e.g. dentist). Therefore, some pre-hospital diagnostics or treatments could be done at home or in a neighborhood community center, at a much lower cost.
  In addition, the humanoid robot would provide the means for a human medical expert to diagnose and treat a patient at a remote location, or even a remote village, through tele-presence. With the humanoid robot, it is possible for us to envision in the future the concept of a virtual hospital.
- *Robot-assisted Education at Home*:
  In our modern society, parents are heavily occupied with their professional activities. There is limited time for parents to contribute to the educational process of their children. In order to compensate for this deficiency, more and more parents rely on private tutors to complement schooling. In the future, an alternative to private tuition may be the use of humanoid robot-tutors, with pre-programmed and selectable knowledge and skills. One obvious advantage to using the humanoid robot as a tutor is the ability for the same humanoid robot to be configured as a tutor in different disciplines, as well as at different skill and knowledge levels. As a result, robot-assisted education is not only appropriate for children, but also relevant to the continuing education of adults. With the humanoid robot, it is possible to envision a virtual university for life-long learning at home.
- *Robot-assisted Tele-existence*:
  The human body is not only a collection of sub-systems for output functions, but also a collection of sub-systems for input of sensory information. The humanoid robot is also a complex system, having output and input functions, and is an ideal platform to extend the reach of a human's output functions, for example, to a remote location. It can act as a "complex sensor" placed at a remote location, feeding back information to humans who can then feel, experience, interpret, respond

etc. This is what the commonly called *tele-existence*. With the humanoid robot, it may be possible one day for humans to travel or shop in a remote place without going anywhere. This type of tele-existence will certainly enrich our lives.

- *Mechanized Buddy*:
  More and more researchers in the community of robotics and artificial intelligence are studying developmental principles, underlying the self-development of mental and physical abilities through real-time interaction between the environment and humans. This research will have a direct impact on the manufacturing of smart artificial animals (e.g. SONY's AIBO, a type of mechanized dog). The animals of the future will possess certain degrees of autonomy to self-develop emotional, affective and cognitive functions through real-time interaction with humans. It will not be long before we will see the market flourishing with smart toys or animals.

1.5.3 *Space Exploration and Military*

The humanoid robot is an ideal platform for tele-presence or tele-existence. Because of this, it is easy for us to imagine its applications in space exploration and the military. It would be possible to dispatch a space shuttle commanded by humanoid robots, yet controlled by humans at a ground station on Earth. It would also be possible to assign humanoid robots to maneuver military land, air, or underwater vehicles in a battle field without risk of human casualty. In the battle against terrorism, humanoid robots could help to prevent, dissuade, and rescue.

1.5.4 *Education*

Today's engineering education emphasizes the integrative aspect of various engineering disciplines, or Mechatronics. Mechatronics originated in Japan in the 1970s and is gaining worldwide attention because of the importance of integrating different, but inter-related engineering disciplines. A formal definition of Mechatronics can be stated as follows:

Definition 1.7 Mechatronics is the study of the synergetic integration of physical systems with information technology and complex decision-making in the design, analysis and control of smart products and processes.

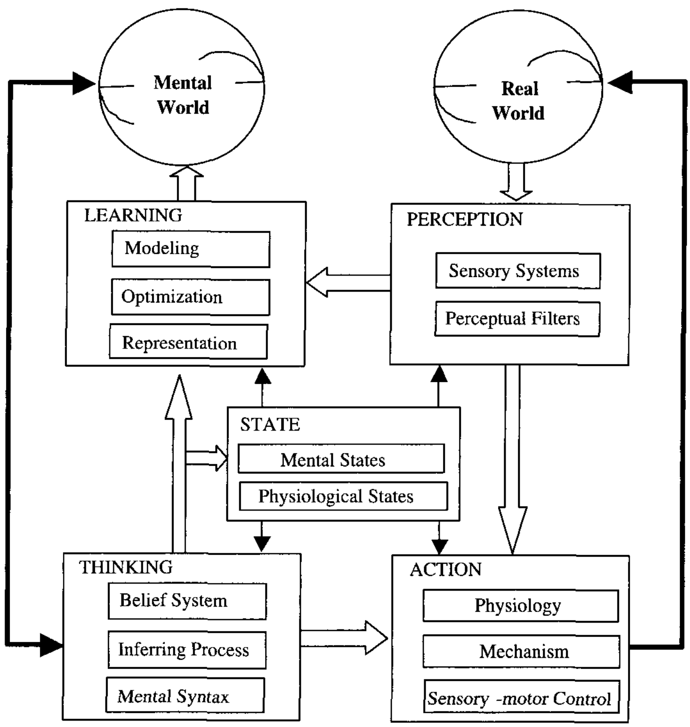

Fig. 1.8 A proposed framework for human intelligence which encompasses four constituent elements: perception, learning, thinking and action.

The humanoid robot, being a combination of mechanical, electronic, control, information, perceptive and cognitive systems, is an ideal platform to illustrate the essence of Mechatronics.

1.5.5 *Research*

Besides education, which propels research on the humanoid robot, two additional forces which simultaneously stimulate research in this fascinating field are: a) computational neuroscience and b) intelligent (physical) systems.

Computational neuroscience is the study of how the human brain plans and controls behaviors to achieve desired results (i.e. outcome). By definition, a "behavior" is a sequence of actions with a specific syntax (i.e. ordered arrangement). Human life is an unceasing journey of achieving desired results through actions which are decided as a result of our internal representations of the real world, our mental state-of-mind, and our physiological state. An important goal of computational neuroscience is to develop computational theories and models from an understanding of the brain's functions in these important areas. (See Fig. 1.8 for illustration).

- *Perception*:
  Humans have five sensory systems, namely: visual, auditory, kinesthetic, gustatory, and olfactory. These sensory systems supply input to the brain to build the personalized internal representations of the external world. In addition, mental and physical states affect the way the brain reacts to certain sensory input.
- *Learning*:
  The human brain has the ability to process filtered sensory data to derive structured representations which form our mental world, in terms of knowledge and skills. Generally speaking, *knowledge* describes the relationships between causes (e.g. stimuli, actions, transformations, conditions, constraints etc) and effects (e.g. results, facts, situations, conceptual symbols etc). However, *skill* describes the association of behaviors (i.e. the ordered sequence of actions) with results. Language is undoubtedly an important component in learning visual, auditory, and kinesthetic representations of the external real world. And, *Learning* is a process for us to gain not only knowledge, but also skills which result in actions. Hence, action is the source of results. We all have similar bodies and neurological systems. If we undertake the same actions under the same mental and physiological states, we can achieve similar results. This form of learning encourages us to effectively imitate successful people.
- *Thinking*:
  Human beings are capable of not only communicating with the real world, but also communicating with the internal, mental world. We all have our own mental syntax (i.e. ordered sequence of mental actions) which conditions our thinking process. Simply speaking, *thinking* is a process of associating causes with, or disassociating them from effects. The thinking process is dictated by our belief system, because *belief* is pre-formed and pre-organized predictions of achievable outcomes. Our belief system also determines the configuration of our mental and physiological states. For example, the belief that one is resourceful places a person in a different state-of-mind than the belief that one is

miserable.

- *Action*:
  The human body is capable of performing actions, driven by our sensory-motor systems. The ordered actions are behaviors acting on the real world for the achievement of desired results. The performance of our sensory-motor systems obviously depends on the body's mechanisms, as well as physical energy which is affected by our mental state. For instance, being vital, dynamic and excited certainly releases more physical energy than being depressed, scared or uninterested etc.

Intelligence and the ability to produce intended results are unique attributes associated with humans. Now, here comes the question of human intelligence. How do we define intelligence? From an engineering point of view, it is constructive to form an objective, precise definition of "intelligence" to prevent it from being misused. One possible definition of intelligence is as follows:

Definition 1.8 Intelligence is the ability to link perception to actions for the purpose of achieving an intended outcome. Intelligence is a measurable attribute, and is inversely proportional to the effort spent in achieving the intended goal.

The study of computational neuroscience not only helps us have a better understanding of the brain's functions, but also helps guide the engineering approaches in the development of artificial intelligence. However, human-inspired artificial intelligence must be tested by an artificial body. The humanoid robot is an ideal testing ground for computational theories or models derived from the study of the human brain's mechanisms in perception, learning, thinking, and action.

On the other hand, *intelligent (physical) system* is the study of computational principles for the development of perception, learning, decision-making and integration in an artificial body. An artificial body requires artificial intelligence in order to adapt to a changing environment for the purpose of better performing the assigned tasks. Undoubtedly, the humanoid robot is a perfect research platform for the study of the embodiment of artificial intelligence with an artificial body.

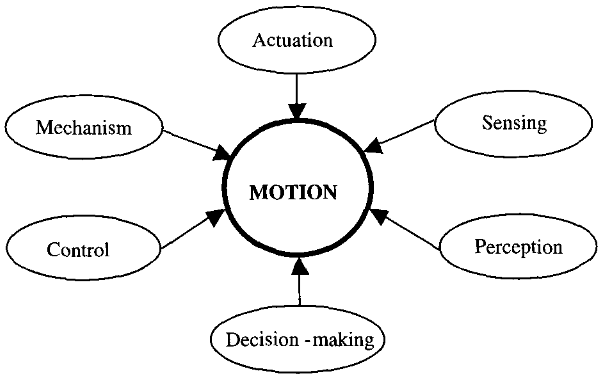

Fig. 1.9 A set of related topics in robotics with a motion-centric theme.

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*