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Soft Computing in Robotics

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ABSTRACT

Soft computing is considered as one of the emerging areas of research in all fields of engineering and sciences. Soft computing algorithms have gained much popularity to solve engineering applications in recent years. These algorithms have gained the attention of researchers in solving problems in robotics, which is becoming inescapable in daily life and attracting extensive applications. The advantages of robots can only be harnessed with their mass introduction in the real world. In this paper, an introduction to soft computing techniques and their application in robotics is provided.

KEYWORDS: *soft computing, hard computing, computer science, robots, robotics, soft robots*

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INTRODUCTION

As computing is increasingly integrated into all aspects of societies and as robotic machines play an ever increasing role in carrying out many tasks that were previously only possible by skilled human labor, there is a growing public awareness on how these developments are influencing almost all areas of our lives, our societies, and our economies. The human-machine integration has led to the development of intelligent systems, such as robots [1]. After decades of research, it seems that robots will finally leave the cages of industrial environment and start working with humans. An example of human-machine integration is shown in Figure 1 [2].

Robotics have experienced a rapid growth over the last decades. Today, several applications benefit from robots. These include manufacturing, industry, health monitoring, efficient logistics, disaster management, rehabilitation, agriculture, aerospace, communications systems, automation, transport systems, and military.

Soft computing approaches are more preferable over conventional, hard methods, for solving problems that are difficult to describe by analytical or mathematical models. Autonomous robotics is such a domain in which knowledge about the environment is inherently imprecise, unpredictable, and incomplete. Therefore, soft computing techniques (such as fuzzy logic, neural networks, and evolutionary algorithms) are beneficial for robotics [3].

The term "soft computing" was coined by Lofti A. Zadeh in 1991. Since then, the area has experienced rapid development. Soft Computing became a discipline within computer science in the early 1990s. The terms "machine intelligence" and "computational intelligence" have been used to have close meaning as soft computing.

The principal premise of soft computing (SC) is that we live in a world that is imprecise and uncertain. Soft computing refers to the use of "inexact" solutions to computationally hard tasks [4].

OVERVIEW OF SOFT COMPUTING

Soft computing (SC) is a branch of computer science that resembles the processes of the human brain. It may also be regarded as a newly emerging multidisciplinary field. Its main objective is to develop intelligent machines in order to solve real-world problems. It differs from the conventional hard computing as it can handle uncertainty, imprecision easily. While conventional hard computing is based on crisp values and binary numbers, SC uses soft values and fuzzy sets.

Soft computing refers to a collection of computational techniques in computer science, artificial intelligence, and machine learning. The techniques deal with development of approximate models in finding solutions to real world problems. They aim to exploit the tolerance of imprecision and uncertainty to achieve tractability, robustness, and low solution cost. Its principle components include:

- Expert systems
- Neural networks,
- Machine learning
- Probabilistic reasoning
- Evolutionary algorithms
- Artificial neural networks
- Fuzzy logic
- Swarm intelligence
- Interactive computational models

These computation methods or technologies provide information processing capabilities to solve complex practical problems. Some of these techniques are illustrated in Figure 2 [5]. Integrating these complementary methodologies results in more powerful hybrid methods than using a single method exclusively.

APPLICATIONS OF SC IN ROBOTICS

Soft computing is used for solving real-life problems and can be applied in different fields such as education, healthcare, business, industry, engineering, power systems, transportation, communication systems, wireless communications, data mining, home appliances, robotics, etc. [6]. Common applications of soft computing in robotics include the following:

- **Soft Robots:** In the past, most robots have rigid bodies for different reasons, such as mobile robot, humanoid and manipulator. A rigid robot has some inherent drawbacks, such as noncompliance causing low adaptability and unsafety and unfriendliness to users. Soft robots provide safe interactions and compliant behaviors. They also are energy-saving as it is normally lighter than rigid robot. Soft robotics has exploded in popularity in recent years. It is one of the hottest topics in robotics. There are some tasks that traditional, rigid robots cannot do. Soft-bodied robots, on the other hand, may be able to interact with people more safely. Robots inspired by biology are becoming common. Biological inspiration does not suggest that we attempt to copy nature. Rather, the objective is to understand the principles underlying the behavior of animals and humans and transfer the behavior int the development of robots. As shown in Figure 3, a bio-inspired "soft" robot is capable of exhibiting substantial behavioral diversity [7]. Soft material robots are elastically soft, versatile, and biologically inspired machines. They are primarily composed of easily deformable matter such as fluids, gels, and elastomers. Abilities such as squeezing, stretching, climbing, growing, and morphing would not be possible with an approach based only on rigid links. A soft robot must adapt its shape and locomotion strategy for a broad range of tasks, obstacles, and environmental conditions. This emerging class of robots could revolutionize the role of robotics in healthcare, field exploration, and cooperative human assistance. For example, some attributes of soft robotic systems make them well-suited for use in human wearables. The proliferation of soft robotics research worldwide has brought substantial achievements in terms of principles, models, technologies, techniques, and prototypes of soft robots. Most of the interest in soft robotics has been limited to robotic grippers, actuators, and flexible computational mechanisms. Soft computing techniques have been applied to robotic grasping [8].

- **Swarm Robots:** Swarm robotics refers to the development of tools and techniques to ease the coordination of multiple small-sized robots towards the accomplishment of difficult tasks. The desired collective behavior of the robots is usually based on swarm intelligence, with the underlying strategy inspired from biological systems such as ants colonies, bird flocks, and fish schools. Swarm robotics is a relatively new paradigm used to control the operation of a large group of physically limited robots. The success of swarm robotics applications may be attributed to efficient use of smart sensing, communication, and organization functionalities, which allow for collaborative information sensing, operation, and knowledge inference from the environment. Swarm robotics have become a major research catalyst of the computational intelligence community. The main advantages of using swarm robotic systems are: (1) Robustness: due to the distributed nature of the swarm, the failure of a single robot does not compromise the integrity and operation of the remaining robots, (2) Scalability: the addition of new robots to the swarm can be made incrementally (without reconfiguring the entire population), (3) Parallelization: complex control is achieved through simple yet concurrently held interactions between the members of the swarm [9,10].

- **Robot Vision:** Although there are many sensors used by robots, one of the most used types is vision sensors. Vision enables autonomous systems to complete complex tasks where environment information is needed. Robot vision is important because it is needed in performing more complex tasks such as grasping, mapping, navigation, tracking, active sensing, and pattern recognition. In each of these tasks, the robot needs to process large amounts of data at a fast rate in order to satisfy real time operation constraints. Soft computing has been widely used in robotics and vision applications. Soft computing algorithms, such as PSO and fuzzy logic, can be used to solve important computer vision problems, like image tracking, plane detection, and pattern recognition [11].
- **Mobile Robot:** Mobile robots are intelligent robots that are capable of navigating intelligently anywhere using sensor-actuator control techniques. They can move, sense, and react in a given environment and are able to perform tasks and navigate without human intervention. Mobile robots perform many tasks such as rescue operation, patrolling, disaster relief, planetary exploration, and material handling. They are increasingly used in many fields such as industry, space, defense, and transportation. A mobile robot operating in an unstructured environment must be able to deal with dynamic changes of the environment. Thus, navigation is important in mobile robotics. There are two types of navigation: global navigation and local navigation. In the global navigation, the prior knowledge of the environment should be available. In the local navigation, the robot can decide or control its motion and orientation autonomously using equipped sensors. Several soft computing techniques (such as fuzzy logic, genetic algorithm, neural networks, and particle swarm optimization (PSO)) have been used to solve the robot navigation and obstacle avoidance problem in the various environments. For example, neural network is one of the important technique for the mobile robot navigation [12,13].
- **Cooperative Robots:** Cooperation is just working together. This can occur even with a group of robots collaborate or communicate. Cooperative robots can perform tasks that are either difficult or impossible to be accomplished by a single-arm robot. Such tasks can be manipulating flexible objects and grasping the objects. Cooperating robots may also increase the productivity in a manufacturing environment. Cooperative robotic systems have also been used in aerospace applications [14].

Other applications of soft computing in robotics include social robots, robot arm manipulators, web robot detection, elastic robotic arm, demining robots, and flying robots.

BENEFITS

It is difficult or if not impossible to design robots for complex systems such as nonlinear, time-varying systems using conventional approaches. Soft computing is a collection of intelligent techniques working in a complementary way to build robust systems at affordable cost. The techniques contribute to one of the long term goal in robotics, to solve the problems that are unpredictable and imprecise namely in unstructured real-world environments. The major benefits of soft computing are: (i) its rich knowledge representation (both at signal and pattern level), (ii) its flexible knowledge acquisition process (including machine learning and learning from human experts) and (iii) its flexible knowledge processing [11].

Robots have the potential for replacing humans in hazardous working environments, such as the cleanup of toxic waste, nuclear power plant decommissioning, mining, space exploration, search and rescue missions, security, and surveillance. They are also used to replace humans in performing repetitive type of tasks, such as automated manufacturing, industrial maintenance, spray painting, and arc welding. These advantages let us to build intelligent systems with a high machine intelligence quotient at low cost. Due to these advantages, robots inspired by nature are becoming common in robotics labs. The increase in adoption of robots is causing the development of new battery technologies that are affordable, safe and longer-lasting.

CHALLENGES

Despite decades after first robot was created, the robotics industry faces many challenges. Several challenges still need to be addressed in spite of the progress made during the recent past. In many robotic applications, it is difficult if not impossible to obtain a precise mathematical model of the robot's interaction with its environment. The lack of precise and complete knowledge about the environment limits the applicability of conventional control system design to the domain of autonomous robotics. It is unrealistic to assume that any learning algorithm is able to learn a complex robotic task, in reasonable learning time starting from scratch [15].

There is still room for further research for the advancement of soft robotics Many soft robotic systems still use rigid components that limit their range of capabilities. A grand challenge for soft robotics is the development of an autonomous and intelligent robotic system fabricated entirely out of soft materials. The development of "smart" soft materials is critical for engineering the next generation of fully soft robots that can easily adapt and conform to their environment. Soft robots have been limited due to their lack of good sensing. Robot ethics is a major challenge [16].

CONCLUSION

Soft computing deals with the design of intelligent and robust systems, which exploit the tolerance for imprecision inherent in many real world problems. Robotics is such a domain in which soft computing techniques are greatly beneficial for robotics. Robots are generally built by associating a mechanical structure, actuators, and their control system. As engineers and scientists look to the future of robotics, they are looking for the best ways to create a robot that is entirely soft, has no hard components, such as batteries and circuit boards, and is not tethered to a nearby circuit system. More information about soft computing in robotics can be found in the books in [17-28] and the following related journals:

- Soft Computing
- Soft Robotics (SoRo)
- Journal of Soft Computing Paradigm
- Applied Soft Computing Journal
- Artificial Intelligence & Robotics Development Journal
- International Journal on Soft Computing
- International Journal of Artificial Intelligence and Soft Computing

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Figure 1 A typical example of human-machine integration [2].

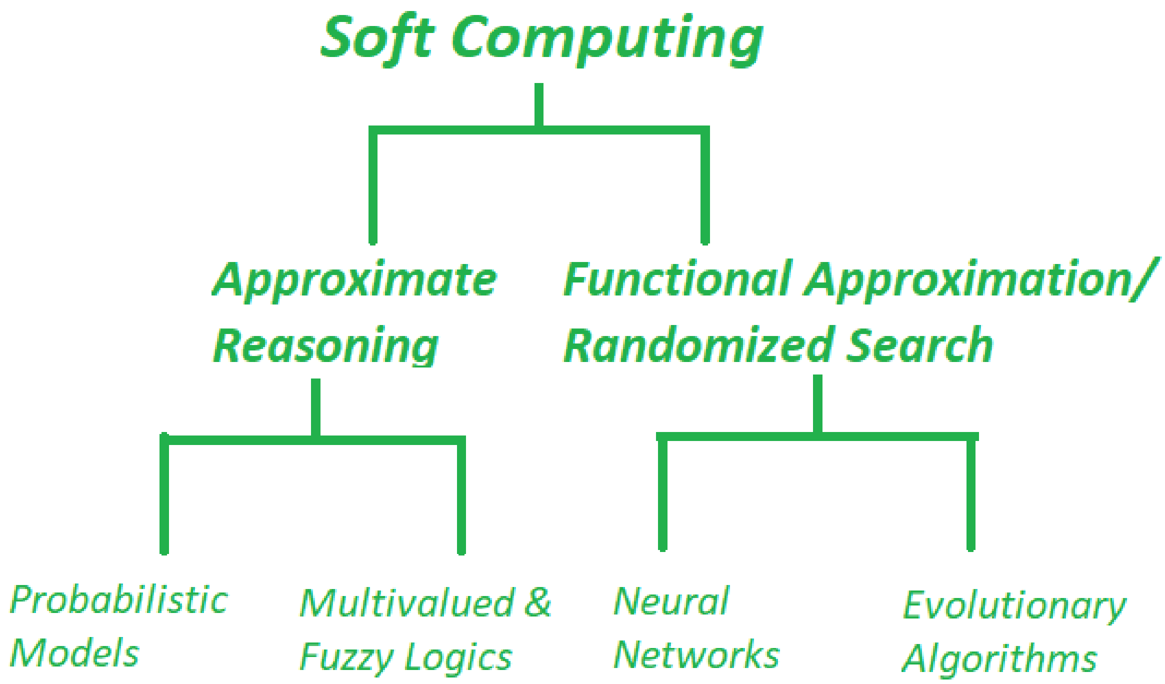

Figure 2 Soft computing approaches [5].

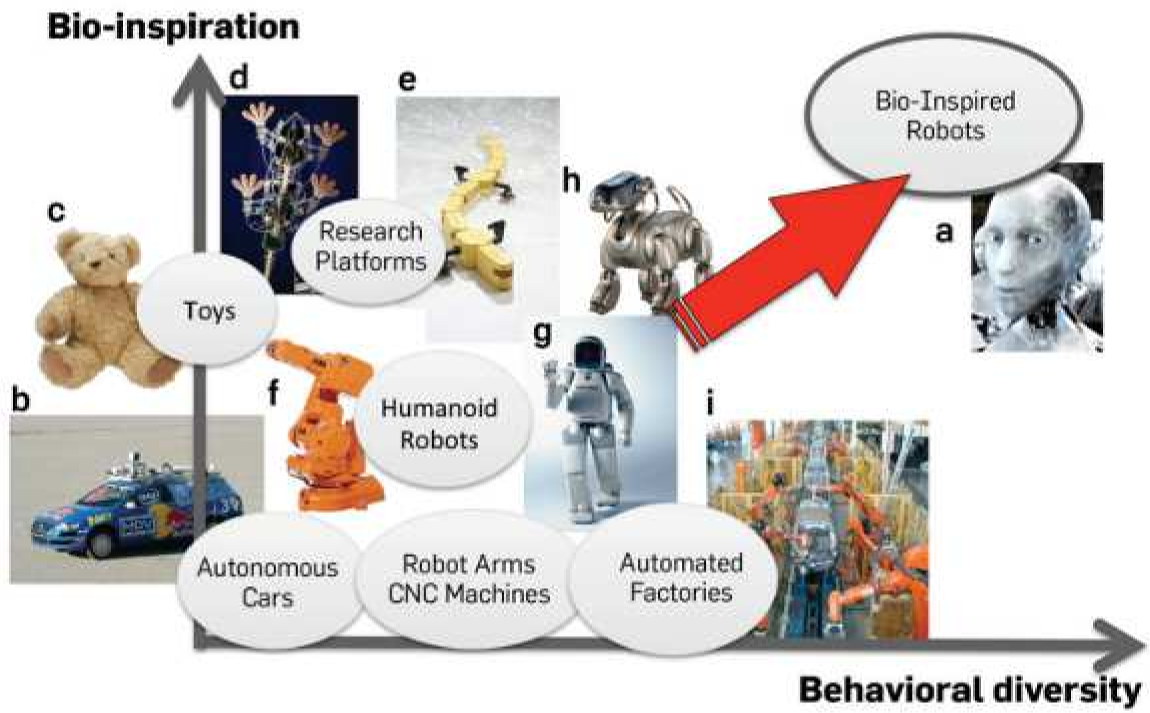

Figure 3 A bio-inspired "soft" robot can exhibit substantial behavioral diversity [7]