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An Overview on the Development and Application of Cognitive Robot

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Abstract. Artificial intelligence has led a new round of scientific and technological revolution, and robots have become a representative product in this era. At present, the development of industrial robots is faster than ever before, and it has driven the continuous breakthroughs in weak artificial intelligence and related industries. Many tasks that used to be done by humans can be done by robots now With the gradual transformation of artificial intelligence is gradually transforming from perceptual intelligence to cognitive intelligence, robots have also opened a new cognitive stage of exploration. Cognitive robot has human-like thinking and logical ability and cognitive learning ability. It can interact with humans and the surrounding environment, and make dynamic responses according to the changes in the environment. It is a complex giant system, involving cross-border cooperation of multi-disciplinary technologies. This paper discusses the system architecture, intelligent perception, human-computer interaction, cognitive computing architecture and application prospect of cognitive robot, proposes a set of cognitive robot system architecture, analyzes the internal working principle of intelligent cognitive architecture, and makes some thoughts on the future development prospect of cognitive robot.

Keywords. Cognitive robot, intelligent perception, human-interactive, ACT-R, cognitive computing.

1. Introduction

The application of artificial intelligence in many industries has driven the rapid development of the robot industry. Although there is no unified definition of robot at home and abroad, the understanding of the composition of robot system is basically consistent. Robot system is composed of robot, working object and environment, mainly including mechanical system, sensing system, control system and drive system[1]-[3]. At present, the existing relevant research work of robots mainly focuses on information acquisition and understanding at the sensing end, path planning and action control of mobile terminals. The research on robot cognition has also made some achievements in cognitive autonomy and cognitive behavior control[4]-[7]. However, there are few studies that comprehensively consider intelligent cognitive computing, intelligent perception and action control from the perspective of robot system.

Cognitive robot is not a mechanical automatic robot in the traditional sense, which is not only an information processing robot that does memory, calculation and reasoning, but a comprehensive high-level intelligent robot with perception, action and learning and

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reasoning abilities. Cognitive robot is composed of multiple intelligent components with cooperative ability, and finally forms comprehensive cognitive ability. Because cognitive robot has advanced cognitive abilities such as cognition, reasoning and decision-making, which are affected by many factors such as environment, human feedback, human prior knowledge and so on. So it is a complex giant system. This paper attempts to propose a system architecture of cognitive robot from the perspective of Qian Xuesen's system engineering, and expounds the relationship between the internal components of cognitive robot, the interaction between cognitive robot and the external environment. At the same time, this paper discusses the working principle of cognitive module, the core component of cognitive robot, and the application value of cognitive robot in society in the future.

2. Cognitive Robot

Many foreign researchers have put forward their own understanding of cognitive robots, and given specific methods including cognitive robot architecture, learning methods, memory systems, etc. K. Kawamura, S.Gordon et al. from Vanderbilt University proposed the concept of cognitive control and designed the cognitive robot ISAC based on the human brain's way of dealing with problems and human's ability to deal with problems. Some human-like cognitive structures and cognitive abilities, such as memory system, were realized on this platform. The cognitive machine Cog was designed by the artificial intelligence laboratory of Massachusetts Institute of Technology (MIT). By drawing on some achievements of brain and cognitive science, many cognitive abilities were realized in Cog, and the concept of cognitive developmental learning was proposed. Heiko Wersing, Jochen J. Steil, et al. of the indigenous European institute believe that online learning is one of the important capabilities of cognitive robots. Although there are few researches on cognitive robots in China, Fudan University has made some achievements in this field, with the birth of Fudan No.1 and Fu Dan Mo.2 autonomous mind development robots. Cognitive robot need to be realized by multi-disciplinary collaborative fusion and utilization. Its core technologies involve image classification, target object detection, speech recognition, natural language understanding, reinforcement learning, etc. (Table 1). In conclusion, it can be seen that cognitive robot is a complex giant system, and its related problems need to be solved under the guidance of system theory. Mr. Qian Xuesen's definition of complex giant system is: “The complex giant system is a system with large scale and complex structure. Its characteristics are that the system not only has large a huge scale and belongs to the category of giant system, but also has a wide variety of elements or subsystems with different nature, complex and changeable relationships. There are multiple macro and micro levels with complex correlation between different levels and unclear mechanism of action. Therefore, it is impossible to infer macroscopic behavior from microscopic description by simple statistical synthesis methods”. Thus, cognitive robot is a complex giant system. All problems that cannot be dealt with by reductionist method, or which are not suitable to be dealt with by reductionist method, and need or should be dealt with by new scientific method, are complex problems [8] - [10]. Therefore, under the guidance of system theory, we should comprehensively consider the interrelationship, interaction and mutual restriction between the components of cognitive robot when solving such complex problems as cognitive robot. In the process of research on key technologies of a certain local component of cognitive robot, the local influence factors shall be optimized and improved in combination with the overall effect. The energy and information exchange between each component of cognitive robot and the whole robot shall be fully considered. At the same time, the influence of external environment on the material, energy and information exchange of cognitive robot shall also be considered.

Table 1. Mainstream algorithms related to cognitive robot

cognitive robot related technologies	mainstream algorithms
image classification	ResNet
target object detection	SSD
speech recognition	RNN-T
natural language understanding	BERT
reinforcement learning	MiniGo

The key technology of cognitive robots is to relate and analyze the perception, cognition, behavior and other parts from the perspective of the whole.. Modern "robotics" provides systematic guidance and help for solving complex problems of robots, including subdividing the types and structures of robots, and analyzing the space description and coordinate transformation of robots, robot kinematics, robot dynamics, robot position and control, robot adaptive control, etc. [2] - [3], which makes the research on robot systems effective. However, the research on robot systems is different from intelligent perception. There are few researches on the integrated architecture of robot systems such as intelligent cognition and motion control. In this paper, a cognitive robot system architecture based on system engineering is proposed, as shown in Figure 1. The system architecture is mainly composed of basic module, intelligent perception module, human-machine exchange module, intelligent cognition module and motion control module. The internal components of perception, exchange and cognition modules are mainly subdivided.

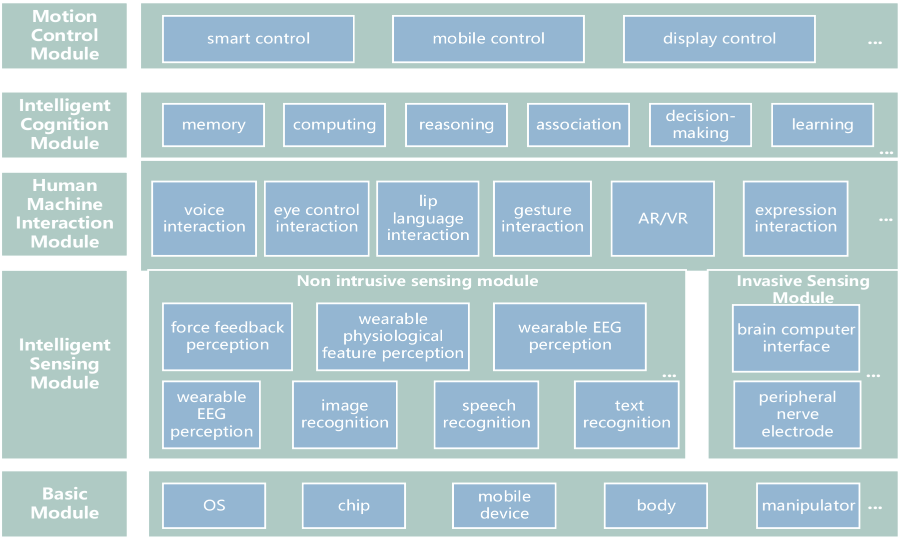

Figure 1. System architecture of cognitive robot based on System Engineering

2.1. Intelligent sensing module

The perceptual channels of cognitive robots are not only limited to sound, vision and hearing, but also include somatosensory, brain sensory and neural channels. Human perception is the communication and transmission of human and external information through human organs and tissues. Human-computer interaction is mainly completed through human perception, mainly including visual perception, auditory perception and tactile perception[6]. The intelligent perception module of the robot is the exchange of material, energy and information between the robot and the external environment by simulating human vision, hearing and touch. It is the basis for the robot to realize intelligent cognition. At present, visual perception and robots are more combined. Through visual perception, we can identify the target, analyze the target behavior trajectory, and then complete the tasks of unmanned driving, robot navigation and customer service. However, the perception ability of a single channel cannot support the goal of intelligent cognition of robots. Mr. Sun Fuchun proposed that "compared with the traditional machine learning technology, cognitive learning emphasizes the simulation of robot's perception and behavior of human brain and human body (hand, eye and body). The cognitive learning of robot is a closed-loop learning process from perception to behavior, and then from behavior to perception. It not only emphasizes the service of perception to action, but also emphasizes the role of action on perception"[1], emphasizing that perception should be combined with human brain, human body and other dimensions. Chella et al. divided robot perception into first-order perception and high-order perception, and proposed that robot self-awareness is based on high-order perception of the robot, first-order robot perception is direct perception of the external world, and high-order perception is perception of the internal world of the robot. And a robot cognitive architecture based on high-order perception is developed. The architecture is divided into three computing areas: the subconscious area involves low-level processing of perceptual data from sensors. In the field of linguistics, representation and processing are based on logical formalism. In the conceptual domain, data from sub conceptual domains are organized in concept categories[11]. Sandini G et al. described a multidisciplinary initiative to promote collaborative research in the artificial cognitive system by developing iCub (an open system 53 degree of freedom cognitive humanoid robot), leading to the meaning of phylogenetic configuration, described the mechanical and electronic specifications and software architecture of iCub. The head and eyes of iCub are fully articulated and have visual, vestibular, auditory and tactile abilities[12]. Madsen O et al. described a robot based cognitive architecture of CiceRobot vision and action. Its core is to integrate visual perception and actions with knowledge representation, so that robots can have a profound understanding of their own internal environment. The principle of integrating perception, action and symbol knowledge is the introduction of an intermediate representation based on Gärdenfors concept space[13].

Although the above intelligent perception plays a certain role in the robot self-awareness model, it does not fully consider the physiological characteristics, EEG(electroencephalogram) changes, emotional changes and other factors of the perceived interaction object - human. These information will help the cognitive robot to improve its cognitive ability through learning and training. Therefore, the intelligent sensing module of cognitive robot should build a non-invasive sensing module and an invasive sensing module around the reaction information of human brain and human body. Specifically, non-invasive sensing includes force feedback sensing, wearable physiological feature sensing, wearable EEG sensing, environmental temperature and humidity sensing, and voice picture recognition. Invasive sensing includes brain computer interface and peripheral nerve electrodes. The intelligent sensing module will eventually acquire human physiological feature information, EEG feature information and environmental feature information.

2.2. Human Machine Interaction Module

Human centered, natural and efficient are the main goals of the new generation of human-computer interaction. The human-computer interaction technology has entered the stage of multi-channel and multi-media intelligent human-computer interaction, that is to say, human's multiple sensory channels and action channels (such as voice, handwriting, posture, sight, expression and other inputs) are used to interact with the computer environment, which can improve the naturalness and efficiency of human-computer interaction[14]. Multi modal interaction (MMI) refers to "a human-computer interaction mode that uses multiple channels to communicate with computers. The channels cover various communication methods for users to express their intentions, perform actions or perceive feedback information, such as speech, eyes, facial expressions, lip movements, hand gestures, head movements, body postures, touch, smell or taste" [14] - [15], it not only adapts to the "human centered" natural interaction principle, but also becomes a necessary channel for the development of cognitive robots.

Among them, voice is mainly used for command control in intelligent robot applications. People control the robot through voice commands. However, voice is not only used to control the behavior of the robot, but also contains rich emotional information, which plays an important role in the research and development of cognitive robots. The technology of speech transcription, voiceprint recognition, speech synthesis and so on is becoming more and more mature, but extracting emotional information from speech still faces many challenges. First of all, emotional psychological state is a very uncertain factor. Its classification standard needs to be based on the maturity and perfection of psychology and psychophysiology. The development of emotional speech needs the help of psychological and physiological research results, involving many disciplines such as acoustics, computer science, linguistics, psychology and physiology. Secondly, emotional speech recognition has not found the most effective emotional speech model and the most effective recognition and classification algorithm. Because the human ear and brain have very good hearing ability for emotional speech recognition, while the recognition ability of the machine is still far from each other, the research results of auditory physiology will help to find the most effective and reliable emotional speech recognition technology. Finally, there are few studies on how to express emotional information in emotional speech between different cultures[16] - [20]. Therefore, it is another challenge in the development of cognitive robots to extract emotional and psychological features from speech signals to judge the speaker's emotions.

At the same time, speech can also realize the effective transmission of experience and knowledge in a non-formal description. It mainly relies on the development of natural language processing technology. Natural language processing technology can now realize deep semantic understanding of human language. As the basic common support technology of cognitive robots, to realize the advanced cognitive abilities of cognitive robots such as emotion analysis, behavior prediction, reasoning and judgment, it needs to combine gestures, expressions eye contact and other common interaction methods between people are difficult to achieve end-to-end semantic understanding.

2.3. Intelligent Cognition Module

Cognitive computing is an important component of artificial intelligence, a computer system simulating human brain, a hybrid of natural language processing, analysis, machine learning and other technologies, and a core sub technology for the development of artificial intelligence to cognitive intelligence[21]· Since IBM's deep blue computer defeated the chess champion Kasparov, in 1996, cognitive intelligence has attracted people's attention[22]. Cognitive intelligence is the basic science of cognitive robot and the advanced stage of intelligent science development. It is based on human cognitive system and mode. The ultimate goal is to imitate human core wisdom and ability. The learning object of cognitive robot is human. Its analysis, decision-making, planning, deduction, route planning, action planning, etc. are inseparable from cognitive computing. The above work is inseparable from a set of reasonable and effective cognitive computing framework [23] - [29].

ACT-R (adaptive control of thought – rational) is a cognitive architecture established by American artificial intelligence experts and psychologists such as Aderson. It is a theory used to simulate and try to understand human cognition. As shown in Fig. 2, it includes multiple modules such as perceptual motion module, objective module and declarative memory module. Fig. 3 shows the information organization in ACT-R5.0. ACT-R attempts to understand how humans organize knowledge and generate intelligent behaviors. Its goal is to enable the system to perform various human cognitive tasks, such as capturing human perception, thoughts and behaviors. The core of ACT-R is descriptive knowledge module and central generation system. The descriptive knowledge module stores the long-term knowledge accumulated by individuals, including basic facts and professional knowledge. The central production system stores individual procedural knowledge, which is presented in the form of condition action (production) rules. When certain conditions are met, the corresponding actions will be executed by the corresponding modules. The continuous triggering of production rules can ensure that each module cooperates with each other and simulate the continuous cognitive process made by the individual. ACT-R has undergone several rounds of development of important versions. In version 4.0, a successful model has been established for cognitive phenomena in the first two fields of the unified domain (i.e., problem solving, decision-making, routine action, memory, learning and skills). In version 5.0, a model has been established for perception and dynamic behavior. ACT-R has now entered version 6.0 and supports different system operating platforms. As a large amount of experimental information, ACT-R theory has been widely used in the field of psychological research and can be directly used in the research of cognitive robots.

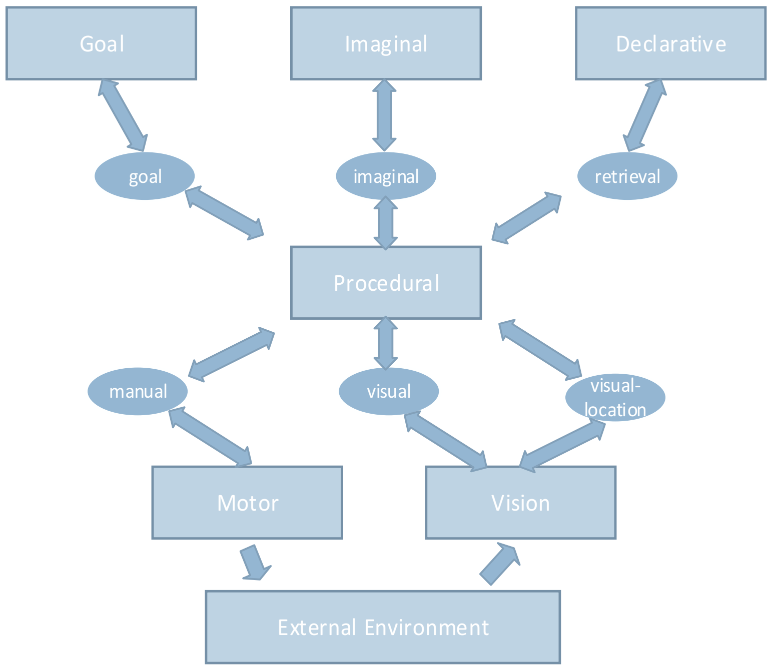

Figure 2. Internal architecture of symbolic system of ACT-R.

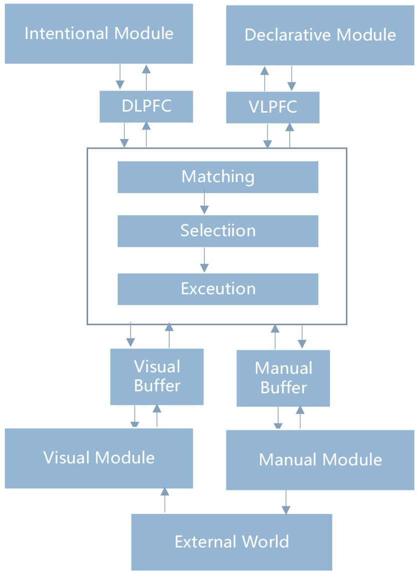

Figure 3. Internal architecture of symbolic system of ACT-R 5.0.DLPFC: dorsolateral prefrontal cortex, VLPFC: ventrolateral prefrontal cortex.

However, human emotion and tacit knowledge are also involved in the cognitive process of human beings. At present, the cognitive computation in the field of artificial intelligence does not involve human emotion and tacit knowledge[30]-[40], nor does Watson, the spokesperson of IBM's cognitive solutions. In view of all these points, this paper constructs an improved robot cognition module based on ACT-R, as shown in Figure 4.

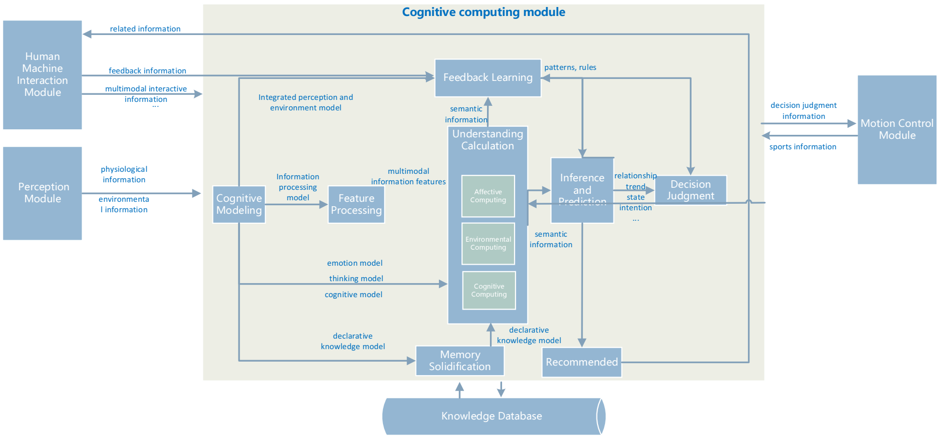

Figure 4. Improved robot cognition module based on ACT-R

The framework includes cognitive modeling, memory solidification, feature processing, understanding calculation, inference prediction, association recommendation, decision judgment and feedback learning. The cognitive module can first build a cognitive model, an emotional model, a thinking model (tacit knowledge oriented), a comprehensive perception model, an environmental model, a declarative knowledge model and an information processing model through cognitive modeling. The relevant models provide input standards for subsequent feature processing, understanding calculation, memory solidification and other links. Secondly, the feature processing is used to extract the physiological information, environmental information, brain signal information obtained by the sensing module and the multi-modal interaction information obtained by the human-computer interaction module in the information layer and the signal layer. In this process, the knowledge that can be described structurally will be stored through memory solidification. Tacit knowledge refers to the comprehensive operation of various types of signals and information using the above-mentioned use models, and is recorded and stored in vectors. The understanding calculation part is mainly used for emotion calculation, environment state calculation, cognitive goal calculation, etc. The calculated information is used for reasoning and prediction in relation, trend, state, intention, etc. The high-order cognitive abilities such as behavior control and decision-making judgment of the robot are comprehensively realized.

3. Conclusion and Prospect

This paper mainly combs and discusses the research progress of cognitive system architecture, intelligent perception, human-computer interaction, intelligent cognition and other related technologies of cognitive robots. At present, we mainly face the following challenges:

(1) The system architecture of cognitive robot still needs to conduct systematic and comprehensive research on perception, interaction and cognition, rather than segmented research at the present stage. There is an inevitable relationship between them.

(2) Intelligent perception still needs to explore how to realize the multi-channel cooperative perception of hand, body and brain. The multi-channel cooperative perception of hand, body and brain will provide more accurate basic cognitive computing information for cognitive robots.

(3) Emotional calculation and human tacit knowledge should be taken into account in intelligent cognition.

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