Computational Intelligence in Robotics and Automation

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Abstract – Robots have been used in many fiels of industry. Robots are regarded to be important for the automation in factory, laboratory, office as well as in space. These robots must have intelligent capability such as adaptation, learning and evolution. This paper deals with these kind of intelligent robot systems.

Recently, computational intelligence including neural network, fuzzy system and genetic algorithm, has been discussed for realizing human intelligence.. Human can get a lot of information from their sensors by hearing, seeing and so on. And Humans can adapt to their external environments by using the information effectively. Furthermore, human can improve the environments to be useful for them. In order to realize these kind of human intelligence, each functions such as perception, inference, decision making, and learning, should be integrated effectively. The intelligence of a robotic system depends on the architecture of hardware and software as a whole system. This paper introduces a robotic system with structured intelligence.

I. INTRODUCTION

In the field of robotics and automation, the intelligent system are required in order to adapt to the dynamic environments. The animals in nature can adapt their environments and they can behave intelligently. In order to realize the intelligence in the robot system, we have to understand the animals fundamental functions.

Animals have eyes, ears, and other organs for sensors. They can get a lot of information from these sensors by hearing, smelling, and so on. And by using the information effectively, Animals can adapt to their. External environment The information acquired by sensing from their external environments is very important and useful for surviving under their dynamic environments. By using the information effectively, animals can learn how to behave and conserve some information as a knowledge, and animals can adapt to their dynamic environments by using their conserving knowledge. Furthermore, animals has hands, legs, mouth, and other body parts for effectors. These effectors are useful to act or adapt to their dynamic environments.

The ability to adapt to the dynamic environments is a kind of intelligence. In the case of human, he can improve the environments to be useful for him. This is more advanced ability compared with the adaptive ability. Animals are good models to realize the intelligent systems. Today, intelligent systems, which perform task autonomously, are required in many kinds of fields such as factories, nuclear power plants, plants, space robots, and medical fields. However, it is difficult for the systems to have a intelligence like animals. To realize the intelligence, systems must have many kinds of abilities such as sensing, perception, knowledge acquisition, decision making, learning, inference and acting functions, and the systems must integrate these abilities so as to adapt to the external environments and given tasks. The integration of the information which is obtained from each function is very important. The intelligent systems must integrate the information which is obtained from their sensors, and act to adapt their external environments by using these information. Furthermore, the intelligent systems must learn how to behave and conserve the learning result as knowledge. The intelligent system need to have abilities to adapt unknown environments and to obtain the knowledge from their sensing information.

With the progress of computation capability, various methods concerning artificial intelligence (AI) have been successfully proposed [1].The ultimate goals of AI are to understand the mechanism of human brain and to realize human intelligence on a machine. The goals are scientific and engineering approaches, respectively. In fact, the problem of artificial intelligence is to describe and build an intelligent agent, which perceives its environment by sensors, make decision and action. To realize

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human intelligence in computer or robotic systems, various methodologies have been discussed so far "TABLE I".

Current robots are often required in critical and dangerous areas for human . To perform a given task, a robot collects or receives information concerning its external environment, and make actions to the environments. Both of the information and actions are often given from human operators, but ideally, the robot should automatically perform the given task without human assistance. To realize intelligence on the robotic system, neural network (NN), fuzzy system (FS), reinforcement learning, genetic algorithm (GA and expert system, have been successfully applied to the various robots. The main role of genetic algorithms on the intelligent robot is the optimization for modeling or problem-solving. In addition, bucket brigade algorithm, Q learning and others, have been discussed as learning method throu the interaction with environment. This kinde of behavior-based AI [1,2] stresses the importance of the interaction between robot and environment, while classic AI is based on therepresentation and manipulation of explicit knowledge. However , the behavior-based approach need to design a new controller for each task [1]. Recently, behavior analysis and training as methodology for behavior engineering, Menials architecture and model-based learning, have been proposed [3-5].

This paper introduces the foundation and methodologies for intelligent robot systems by learning, adaptation and evolution.

First, we introduce FS, NN, GA and their synthesis techniques for realizing learning, adaptation and evolution. Next this paper introduces a hierarchical intelligent control architecture. The hierarchical intelligent control consists of three levels: 1) adaptation level, 2) skill level, and 3) learning level. This scheme has two characteristics with respect to learning process: top – down approach and bottom-up approach . In order to link three levels and have such characteristics for knowledge acquisition, the scheme uses AI, FS, NN and GA [6-8]. Next, A robotic system with structured intelligence are introduced[9]. Based on the perceptual information, a robot with structured intelligence can make action from four levels in parallel.In addition, the robot generates its motion through the interaction with evironment and at the same time gradually acquires its skill based on the generated motion. Here skill is defined as facility which can generate good motions. To acquire skill and motion, the robot requires two types of evaluations: external evaluation and internal evaluation.

As another approach, self-organizing cellular robotic system (CEBOT) which is composed of a number of autonomous robotic units with simple functions are proposed[10-12] .Each robot has only a simple function. However, by combining or cooperating each other, multi-function are realized. And the intelligent group behavior can be generated. Furthermore self-organizing manufacturing system(SOMS), in which processes effectively self-organize according to other processes have been proposed[13]. The SOMS is based on the concept of CEBOT which is composed of a number of autonomous robotic units with simple functions. SOMS is very flexible manufacturing system. And SOMS can produce many kind of products by self-organizing the machines.

II. THE FUNCTIONS FOR INTELLIGENCE

Considering the animals living in the nature will make clear about the intelligence. Animals can get a lot of information by hearing, seeing, smelling, and so on. And by using the information effectively, Animals can adapt to their dynamic environments. This is a fundamental ability of the Animals. Furthermore, in the case of human, he can improve the environments to be useful for him. This is more advanced ability compared with the adaptive ability.

From the view point of intelligence of animals in nature, the systems, which are able to adapt to the dynamic environments, are the basic intelligent system.

More intelligent systems like a human can improve their environments to be useful for themselves. Therefore, the important fundamental functions for the intelligent systems are shown as follows.

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(1) The sensing ability
(2) The perceptive ability
(3) The knowledge acquisition ability
(4) The learning ability
(5) The inference ability
(6) The decision making ability
(7) The acting ability

The sensing ability is to get information from the external environments and the internal state of the systems. It is very important to get information from the external environments and internal state of the systems because the systems can recognize the change of environments and the state of themselves through the information from their sensors. The perceptive ability is to

interconnected neurons with input, output, synaptic strength, and activation. The neural networks can be divided into two types; feed-forward and recurrent networks. A feed-forward network has input layer, hidden layer, output layer and unidirectional links between neurons, while the recurrent network has feedback links between neurons. The learning algorithm is, in general, determined by the teacher type from the environment. The learning algorithms for adjusting weights of synaptic strength are classified into supervised learning with target responses, unsupervised learning without target responses, reinforced learning only with the response of success or failure. In general, a multi-layer neural network is trained by a back propagation algorithm based on the error function between the output response and the target response (Fig.3). However, the back propagation algorithm, which is known as a gradient method, often misleads to local minima. In addition, the learning ability of the neural network depends on the structure of the neural network and initial weights of the synaptic strength. Therefore, the optimization of the structure and the synaptic strength is very important for obtaining the desired target response Other artificial neural networks are Hopfield network and Boltzmann Machine. Hopfield network is regarded as an autoassociative fully connected network which has symmetrically weighted links. Boltzmann Machine is based on the simulated annealing according to Metropolis dynamics.

Fuzzy theory and fuzzy logic, which was proposed by L.Zadeh, provide us the linguistic representation such as 'slow' and 'fast'. Fuzziness is often confused with probability. A statement is probabilistic if it expresses a likelihood or degree of certainty or if it is the outcome of clearly defined but randomly occurring events. On the other hand, the fuzzy expresses a degree of truth, which is represented as a grade of a membership function. The fuzzy logic is a powerful tool for nonstatistic and ill-defined structure. Fuzzy inference system is based on the concept of fuzzy set theory, fuzzy if-then rule, and fuzzy reasoning. The fuzzy reasoning derives conclusions from a set of fuzzy if-then rules. Fuzzy inference system implements mapping from its input space to output space by a number of fuzzy if-then rules. The widely used fuzzy inference systems are Mamdani fuzzy models and Takagi-Sugeno fuzzy models, which are used as fuzzy controllers. The feature of the fuzzy controller is the locality of control and the interpolation among local control laws. In the fuzzy controller, the state space of the system is divided into some regions as membership functions which are antecedent, and the output (consequence) for the system control is designed as singletons or membership functions. Next, the fuzzy rules are interpolated as a global controller. However, fuzzy theory and fuzzy logic have no tuning methods for fuzzy rules and human experts have generated and tuned the membership functions and fuzzy rules so far. Therefore, we require optimization and learning methods to obtain optimal fuzzy rules. The learning of fuzzy systems can be basically classified into three categories; (1) structure learning which optimizes the combination of fuzzy rules, (2) antecedent part learning which optimizes the shapes of input membership function, (3) consequence part learning which optimizes the output of fuzzy if-then rules frequently defined as singletons. Of course, the combined optimization can be considered.

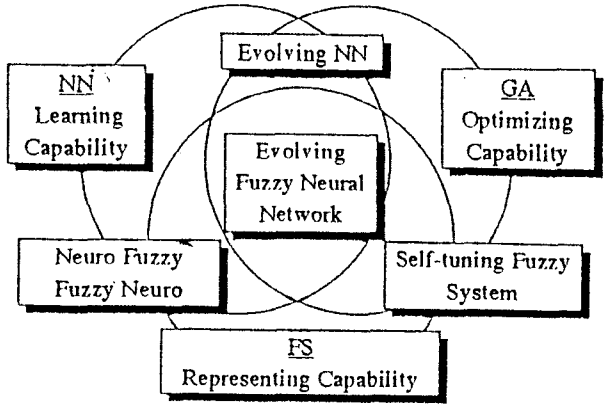

Fig.2 Synthesis of NN,Fuzzy and GA

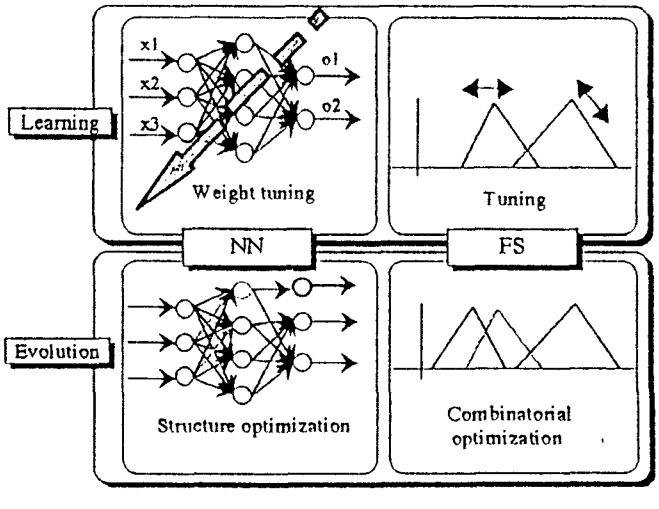

Fig.3. Learning and evolution of NN and fuzzy rule

TABLE I FEATURES OF SOFT COMPUTIONG AND RELATED

recognize the sensing information from their sensors. Only the useful information from their sensors are selected and used to recognize the external environments and the state of themselves. Sensing and perception ability are needed to recognize the external environments. The recognition of external environment is to know or identify from the past experience or knowledge on the basis of the input and output from the environment. The knowledge acquisition ability is to conserve the sensor information and actions which the systems act successfully as knowledge. Here knowledge means data or procedures that are given as truth for an objective and also includes the law of physics and mathematics. The knowledge acquisition includes how to represent knowledge and how to store knowledge. The representation of the knowledge is very important and it is a difficult problem. The learning ability is to acquire the way of adapting to the environments. In other words, learning is the process to acquire knowledge or skill based on the information acquired from external environment, and especially, the learning is to acquire inference rules as knowledge. One of knowledge-based inference systems in the artificial intelligence is an expert system. The expert system is generally defined as a program that uses available information (knowledge), heuristics, and inference to propose solutions to a special problem. The inference ability is to predict the effect of the actions. In the case of human, he can improve the environments to be useful for him. Human can evaluate the effectiveness of his actions and the change of environments. This kind of inference ability is more is more advanced intelligence. The decision making ability is to determine how to behave by using knowledge and percepted information obtained from the sensors. Here, decision making includes planning and motion generation. The acting ability is to adapt to the external dynamic environments and to act on the external dynamic environments. Each ability has a relation organically with the other abilities through the information from the sensor and knowledge database. The information obtained from the sensors are percepted and One information is used to determine how to behave, other information is conserved as the knowledge, and the other information is used for learning and predicting.

The ultimate goals of the intelligent systems are to understand the mechanism of brain and to realize human intelligence on a machine. Each goal is scientific and engineering approach, respectively. In fact, the problem of intelligent systems is to describe and build an intelligent system, which perceives its environment, make a decision, and performs action. Here the environment includes deterministic, dynamic and continuous elements. The intelligent systems will be realized by integrating these abilities . The basic concept of the intelligent system is displayed in Fig. 1.

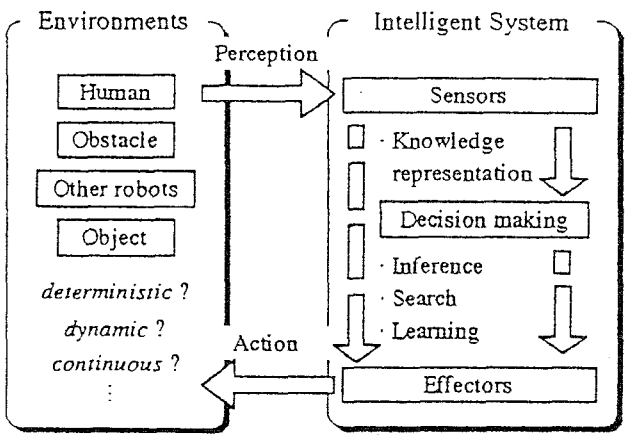

Fig. 1 Intelligent Systems interaction with various environments

III. SOFT COMPUTIONG FOR COMPUTATIONAL INTELLIGENCE

The main problem to realize the computational intelligence is how to integrate these information obtained from the functions. Soft computing is one of the methods to integrate the information. Soft computing, which was proposed by L.Zadeh, is a new concept for information processing and its objective is to realize a new approach for analyzing and creating flexible information processing of human such as sensing, understanding, learning, recognizing, and thinking.

As methodological approaches of the soft computing, there are neural network, fuzzy systems, evolutionary computation, machine learning, conventional artificial intelligence and so on (Fig 2).

Artificial neural network simulating the biological neural network can be trained to recognize patterns and to identify incomplete patterns. These training and learning featuresmake neural networks suitable for applications in pattern classification, signal processing, control, and so on. The basic attributes of neural network are the architecture and the functional properties; neurodynamics. Neural network is composed of many

Knowledge Representation	Natural Language, communication Language, Programming Language If-Then Rule, Fuzzy If-Then Rule
Inference	Production System, Fuzzy Inference System Artificial Neural Network, Classifier System, Belief Network
Learning	Back-Propagation Learning, Reinforcement Learning Temporal Difference Method, Q-Learning, Bucket Brigade Algorithm
Search	A* Search Heuristics, Branch-And-Bound Method, Dynamic Programming Line Search, Steepest Descent Method Hill-Climbing Search, Genetic Algorithm, Simulated Annealing

Each technique plays the peculiar role in the soft computing and related fields are shown in "TABLE I". However, there are not complete techniques for realizing all functions, and therefore, we can integrate and fuse some techniques to overcome the disadvantages of each techniques. These techniques of soft computing are useful to integrate a lot of information and to conserve the information as knowledge.

IV. ROBOT SYSTEM WITH STRUCTURED INTELLIGENCE

In the field of robotics and Automation, the intelligent robot are required. In order to realize the computational intelligence, many architecture has been proposed. In this section , we propose the robot system with structured intelligence.

The intelligence of robot system depends on the architecture of hardware and software as a whole system. The previous section introduced the hierarchical intelligent control constructed from the viewpoint of methodology in the intelligent system.

This section introduces robotic system with structured intelligence constructed from the viewpoint of cognitive psychological features.

An intelligent robot requires close linkage of perception, decision making and action. In order to realize the this linkage, the structure of intelligence as a whole system is very important, since the flexibility and learning capability depend on the structure of the whole system. The intelligence of the robot emerges as the result of integration of local modules by global learning. The evolution of the structure emerges advanced intelligence and function. "Fig.4" shows the architecture of a robotic system with structured intelligence. A robot receives sensory information, and recognizes quantitative information of the environment. Next the robot perceives its external environment through interpretation into qualitative information by sensor fusion/integration and focus/release of selective attention. Based on perceptual information from environments, the robot makes action from four levels in parallel. The action levels are reactive motion level, skilled motion level, primitive motion planning level and motion planing level. When the robot recognizes dangerous quantitiative information from external environments , the robot makes reactive motion (reflex). This action level requires no decision making. In the skilled motion level, the robot performs fundamental motion

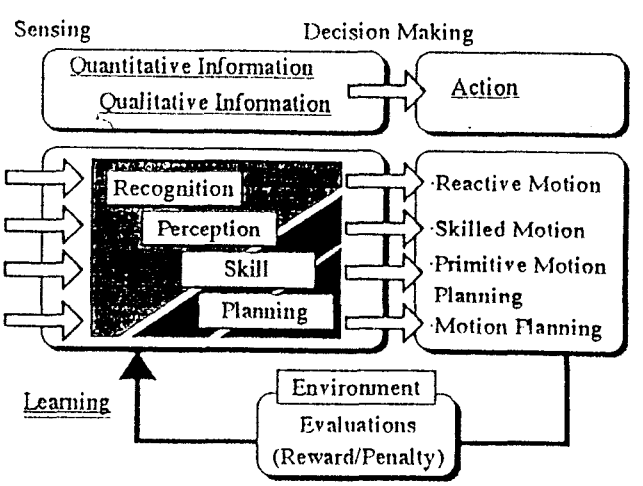

Fig.4 Architecture of a robot with structured intelligence

such as locomotion and transportation based on the simple decision making. In addition, when the robot has no skill, the

robot must generate its new motion. If the robot can combine its simple skill, then the robot simply generates its new motion by combining .However, if the robot has no motions and skill, the robot generates new motions by motion planning. Thus a robot has no skill at initial state, but gradually acquires skill and motion through the interaction with environments.

In order to acquire skill and motion, the robot requires two types of evaluations. "Fig.5" shows these evaluations. The first one is external evaluation through the interaction with environments. The external evaluation is basically used for generating primitive motion. The other is internal evaluation for binding the robot's primitive motions recursively. The internal evaluation is used for planning and decision making from meta-level based on the primitive motions and external evaluation. In fact, human consciousness can be coinscious of being conscious recursively. This causes human to predict and infer through the recursive knowledge based on the internal evaluation and external evaluation through the interaction with the environment. Consequently, the robot can generate structured intelligence by binding perceptual information and its motion from various levels. Actually , the robot performs planning and learning based on these evaluations for adapting to the environment.

In order to realize the robot system with intelligence, Soft computing techniques can be applied. In the motion planning level, the robot basically can generate new motions by GA. We have proposed various trajectory planning methods by

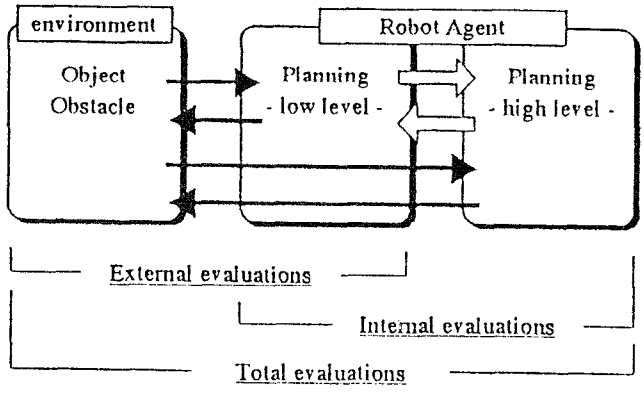

Fig.5 External evaluation and internal evaluation for robot

GA[9][14]. Hierarchical trajectory generation method for intelligent robots is based on the concept of external and internal evaluations. The hierarchical trajectory generation method can easily generate a collision-free trajectory by combining some configurations of the robot. In addition, the robot with structured intelligence acquires skill and knowledge for recognition and inference based on the motions generated by the motion planning and perceptual information by sensing. Inference based on the motions generated by the neural networks and fuzzy inference rules. Therefore to adapt to dynamic environment and perform new tasks, the robot generates required motions by planning ,and at the same time, the robot needs to change the inference and association mechanism, that is, the simultaneous processing of planning and learning make a robot intelligent.

Furthermore, when the robot has many behaviors against sensory information, the robot should select the best one. In this case, stochastic learning automaton is applied for decision making . The learning automaton can learn how to select the best behavior, when the environment has stochastic property. In this way, the robotic system with structured intelligence gradually evolves toward complex system from simple one through the interaction with dynamic environment by NN, FS, GA and other techniques.

V. SUMMARY

In the field of robotics and automation, many intelligent architectures have been proposed in order to realize the intelligence. Robot System require information representation of knowledge and skill to realize intelligence like animals, and moreover, require structured intelligence to realize advanced information processing..

This paper describes the fundamental functions required for intelligent systems. and methodologies for intelligent systems, and introduces learning, adaptation and evolution for intelligent system. The synthesis of neural network, fuzzy system and genetic algorithm is important for advanced information processing and structured optimization.

Further more, this paper introduced the robot system with structured intelligence, which is constructed from the view point of cognitive psychological features. The intelligence of a robot system emerges as the result of integration of local modules by the simultaneous processing of perception, learning, decision making, search and planning. Comparing with Animals, an intelligent robot system has an advantage that the robot can reorganize itself by exchanging functional components, while the robot maintains each function as a whole. Structure

optimization of robotic system is very difficult to solve. Local structure optimization can be realized by incremental learning and others, but robotic system requires global structure optimization as the structure gradually grows by learning, adaptation and evolution. Self-organization and evolutionary computation are required for realizing stable and optimized structure of intelligent system for information processing.

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