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A New Modeling Method for Intelligent Service Mobile Robot

[1]Wei Xie, [2]Jiachen Ma, [2]Mingli Yang, [1]Qi Zhang and [2]Huiying Gao
[1]State School of Astronautics,Harbin Institute of Technology, Harbin 15001, China
[2]Department of Information Science and Engineering Harbin Institute of Technology at Weihai, Weihai 264209, China

Abstract: In order to solve the current difficulties of modeling for designing Intelligent Service Mobile Robot (ISMR),a new modeling method based on metasynthesis is proposed from the macro and micro levels. And the system analysis and design agent-oriented based on POMDP are provided in the same time. Finally, the two case studies are given and the experimental results have shown efficiency and rationality of this modeling method.

Key words: Agent-oriented, comprehensive integration, hybrid intelligent system, ismr, modeling

INTRODUCTION

According to the International Federation of Robotics (IFR), service robot is a robot which operates semi or fully autonomously to perform services useful to well being of human and equipment, excluding manufacturing operations (Xie *et al.*, 2010a). In recent years, more and more people have researched in this area (Chella *et al.*, 2010). Now Intelligent Service Mobile Robot (ISMR) is mainly used in the fields such as cleaning, entertainment, education, rehabilitation of older persons and nursing, which can help people finish specific task successfully. Some examples have shown it can assist people successfully such as housekeeping, entertainment and surveillance (Muciente *et al*., 2010). But how to design an ISMR efficiently and scientifically is a challenging work. After all, the robot is classical information system and complex system, so its core problem is the system modeling. So far, there are still no unified modeling methods for it because of the complexity of applications. The lack of integrated methods of modeling leads robotic developers to analysis and design systematically so hard.

In order to solve those problems, many scholars have provided lots of solutions from the perspective of intelligent control and AI. The designs of intelligent system have become the direction of robotic development. But with the increasing complexity, the traditional modeling methods such as AI, pattern recognition and control theory have not met the needs of perception and cognition. Therefore, the modeling methods of integration based on hybridization intelligent system have become an effective way to design robotic system.

Compared to general robot, the high degree of autonomy is desirable for designing ISMR. They mainly provide services to people or finish complex task through collaboration with people. So it has other new features as show below (Xie *et al.*, 2010b).

- Intelligent demanding
- Module versatility
- Friendly human-robot interaction
- High security

Intelligent demanding is the most important feature, because robotic intelligent behaviors can help people solve complex questions .In order to improve robot intelligence, people have provided many modeling methods for building intelligent robot according to three primitives including S, P and A. On this basis, classical deliberative paradigm (Simon, 1981), reactive paradigm (Brooks, 1986) and hybrid paradigm (Brooks and Kaupp 2007) are proposed. The hybrid intelligent paradigm has brought new vitality for designing robot. Under this architecture, the modeling method based on comprehensive integration becomes naturally a new way to solve the problem.

In research of mechanism of architecture of robot, modularity is a difficult problem, so there are many researchers to replace modules with agents recently for constructing robotic system (Carmine *et al.*, 2006). The Multi-agent System (MAS) mechanism based on distributed control has provided a new thought for modeling. Compared to the component-based frameworks, agent-based architecture may represent a means for introducing autonomy, distribution, collaboration, and other advanced features in robotic programming.

From the perspective of the robotic engineering, there are often two ways (centralized and decentralized) to realize the hybrid paradigm in practice. Under this

Corresponding Author: Wei Xie, State School of Astronautics, Harbin Institute of Technology, Harbin 15001, China

architecture, the agent-oriented computing is expected to become the new paradigm. Viewing from the current development trend of robotic system analysis, the hybrid paradigm and distributed architecture based on agent will coexist in the domain of design robot. No matter what kind of computing model you use, the basic problem to solve is seeking for the mapping (also called a policy (Brenna *et al.*, 2009)or model)between world state (S) and actions (A). In the ISMR system, the environments are so complex that they are so difficult to model by linear or nonlinear equations. In particular, the intelligence of robot is reflected by the policy. So we must explore new modeling methods to derivate this policy.

From the perspective of artificial intelligence, there are three study mechanisms including symbolism, behaviorism and structuralism. The applications of these techniques make robot have reasoning, learning and sensor-action functions. It is an effective way for eliciting policy through robot learning techniques such as learning from demonstration (Ltd.) (Brenna *et al.*, 2009), Reinforcement learning and unsupervised learning. In addition, some soft computing method including fuzzy compute, Genetic algorithm and neural computation have been used widely in conjunction with AI and control theory. Those have shown that comprehensive integration is inevitable trend for modeling robotic system.

Previous studies mostly trend to subsystem design or sub module design, and they are lack of system analysis and design strategy from two angles including architecture and intelligence. And the methods rial and error and epeated optimization are main design approach (Nethmzow, 2006). So in this paper, the new comprehensive integrated modeling approach is provided for analysis and design of ISMR. This approach is expected to address the following two questions.

- How to design architecture of ISMR based on metasynthesis
- How to model under this architecture for robot

This study presents a new methodology which guide us to model robotic system from the macro (system architecture) and micro levels (basic model-agent). And we expect to seek for common modeling method of building intelligent robotic system scientifically.

COMPREHENSIVE INTEGRATED MODELING APPROACH

Metasynthesis: Metasynthesis is provided by Cao and Dai (2008), which embody the comprehensive integrated process from qualitative to quantitative. This scientific methodology emphasizes dialectical unity of the system theory including reductionism and holism, and it is used to deal with open complex giant systems. It not only fuses variety of techniques, but also considers people as part of the system. And man-machine division of labor may play to their strengths. Comprehensive and integrated solution process is actually complementary design process of multi-objective from multi-angle (Cao and Dai, 2008). As for ISMR, it is a classical human-machine symbiotic intelligent system. Human can interact with robot each other and enjoy the robot service. Even complex problems are solved through collaboration. This shows that intelligent robotic system is typical platform for studying complex system. Therefore, Metasynthesis are suitable for guiding the robot system design.

According to the features of ISMR, inspired by the metasynthesis, the ways and means of achieving comprehensive and integrated are concluded as follow:

- Integrated multiple models (AI, soft computing, learning, hardware computing etc.)
- Integrated multiple design methods (top-down, bottom-up, centralized and distributed architecture, etc.)
- Interdisciplinary (control, vision, mechanics, AI, IT, EE, etc.)
- Man-machine combination (interaction among robot, human and environment)
- Combination of qualitative and quantitative (human and robot)
- Hybrid (deliberative and reactive) intelligent organization

In the ways proposed above, it can be seen that if there are not systematical modeling methods, it is almost impossible to build a robotic system. Design difficulties mainly are reflected in the integration and complementary of multiple models, design methods and interdisciplinary. In other words, we must integrate robotic system from different layers such as computing model, perception, cognition, learning and interaction. Those have provided three imensional modeling thought for building ISMR.

Basic model: In short, the basic model of robotic system is a mapping between world state (S) and actions (A) as shown in Fig. 1. The basic model is expressed as (1). Traditional approaches depend heavily upon the accuracy of the world model, but now advanced algorithm including soft computing and learning make the policy $\pi = f'()$ easier realize and control with no model. States of environment can be modeled as a function env: $S \times A \rightarrow S$, $s_n \in S$, and $a_n \in A$. The mapping or policy of basic model is described by discrete event state model Q (s,a).

$$\pi = f^{\cdot}(): S \longrightarrow A \quad (1)$$

Classical soft computing is fuzzy logical and neural network which are used to solve nonlinear mapping problem. During the process of seeking for mapping

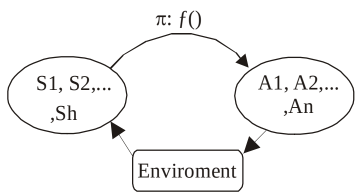

Fig. 1: The basic model of ISMR

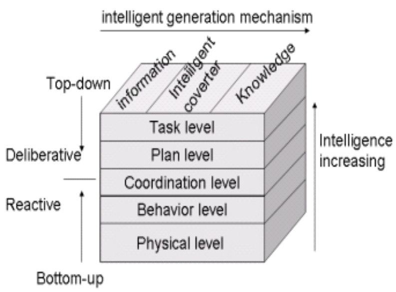

Fig. 2: Comprehensive integrated model of ISMR

function, fuzzy logical is used widely. The design methods through look-up table based on hand experience may meet the needs of real-time. It has an advantage of dealing with various situations without analytical model of environments and combining qualitative and quantitative analysis. During the design process of reactive intelligence, the look-up table (Q (s_i,a_i)) is equivalent to the intelligent core unit to response real-time accordingly to the external environment. Fuzzy logical system is able to cope with unreliability, uncertainty and lack of robustness. But the design of calculating the look-up table is a difficult and highly time consuming task. In addition, there are many subjective factors which are added to system design, so some other algorithms such as evolutionary and neural networks are fused to increase the generalization ability.

Learning is the main features of intelligent. The goal of learning is to prepare it to deal with unpredictable situations and circumstances in its environment. The Lfd(9) and reinforcement learning are used to derivate the policy through reward function (R(s)).

From the control point of view, the system model is expressed as a nonlinear function (2):

$$\dot{x} = f(x, \pi()) \tag{2}$$

X is the continuous valued state vector, If let u= π (x,a,t), the formula (2) is shown as:

$$\dot{x} = f(x, \pi(x, \alpha, t) \tag{3}$$

is specific parameters in the policy π that need to be adjusted by learning the learning ability, and the level of intelligent robotic system is improved like this.

In short, the basic model of the design core is seeking for the core mechanism of the intelligent generation $\pi = f'(\,)$, which can be understood as mapping function, system model or plans strategy. In addition, the environment is complex and even unknown, so the sensor states (s_i) is not fully oberservable. Supervised and unsupervised learning both play important roles in robot learning, but it is often difficult to get enough samples from unknown environment. Therefore, trial-and error unsupervised learning is more applicable for robot learning.

Comprehensive integrated model of ISMR: From the analysis of basic model above we can see that the robotic system may be decomposed into basic analysis model, and this is the basis for problem solving. If we want to increase the system self-learning ability and intelligence, traditional passive modules have not met the need of intelligence. Therefore agent is introduced to take place of module for solving the generalization problem. According to this idea, the basic unit of robotic architecture is considered as an agent, which decouples among hardware and software, function and modules. Corresponding, the architecture of agent is also divided into three typical architecture including deliberative, reactive and hybrid. Like this, every agent may design independently. And these agents are independent and of self-awareness, so the strategy of solving practical problems is performed through cooperation and competition among them.

The next question is how to divide agents. According to features of ISMR and the principle of division igh cohesion, loose coupling the divisions of agents for ISMR are shown as Table 1(Xie *et al*., 2010 b).

If we design robotic system on the basis of Table 1, the next task is how to comprehensively integrate those subsystems. Previous robot system architecture model often concentrates on smaller, areas within the field (Yavuz, 2007), therefore, in this stuely, we provide full three-dimensional integrated reference model including information process, level structure, control system and intelligent generation mechanism as shown in Fig. 2.

As can be seen from Fig. 2, in the space of the layered architecture, both vertical and horizontal dimensions are used to build the analytical framework. Under this all-wave architecture, it is easy to form a comprehensive integrated system of division and interaction. Therefore, this architecture model has reflected the full range of intelligent frame structure of system content.

MODELING METHODS OF ISMR

Merits of agent-oriented modeling: Agent is an advanced computing, if we compare with the traditional numerical analysis method. It not only provides modeling

Table 1: Division of agents for ISMR

Rank	Agents type
Learning	Reinforcement, Teaching and playback
Deliberative	HRI, Command, Blackboard, Emotion Remote middleware, Speech recognition, Image recognition,
Reactive	Navigation, Obstacle-avoiding, Cruise Safe interlock, Charge
Action	Mobile motion, Arm motion, Head motion, Remote control
Sensor	Infrared, Ultrasound, GYR, Pose, GPS Photosensitive, Optical encoder Sound, Camera, Gustation

methods, but also gives solution of the problem. In particular, agent-oriented system may deal with complex interactions between environment and the robot. Now more and more people think that the intelligence of robot is increased in these interactions.

Recently, the complexity of intelligent system based on agent is reflected in three aspects, which include environment, interaction and task. A general agent should have not only the following attributes including autonomy, reactivity and proactiveness, but also have mind attributes including belief, knowledge, intention, commitment, desire and goal.

As for an ISMR, after the basic modules are replaced by agents, the next issue to be faced is how to determine the agent architecture which proposes the agent operating mechanism and organizational relationships. Under the comprehensive integrated model of ISMR as Fig. 2, the architecture of agent are mainly divided into five types which are sensor, action,reactive,deliberative and learning ,and those agents achieve complex problem solving through coordination and cooperation among them.

The environment faced by robot usually inaccessible, nondeterministic, dynamic and continuous, therefore, now there are not mainstream theory in designing MAS. The environment includes not only external state but also internal state. Under this agent-oriented model, the robot learning problem is easily formulated mathematically as an optimization problem in the Reinforcement Learning (RL) as seeking for policy $\pi = f'(\ )$. In the RL model, the interaction between agents and environment may be addressed as MDP (Markov Decision Process). The problem of modeling is converted into synchronous finite state automatic machine design.

Interaction model of agent based on POMDP: During the interaction between agent and its environment, the sensor states (s_i) is not fully oberservable because of the complexity and uncertainty for environment. With the increased complexity, the RL based on MDP may bring dimension disaster problem. Cassandra (Vasilyev, 2002) introduced environment observation, and then Partially Observable Markov Decision Process (POMDP) is used to express interaction between agent and environment.

$$POMDP_{AEI} = \langle S, A, T, R, O, D \rangle \quad (4)$$

S Limited set of environmental conditions
A Effective set of executable actions in interaction
T Probability conversion function, show the probability from S_t to S_{t+1} after execute a_t
$O(s_t, r_t)$ Limited set of relation to S_t and r_t
r_t Reward function
$D(a_t, s_{t+1}, d_{t+1})$
After executing at,, the probability of observable d_{t+1}

$$D = P(o|s'a \quad (5)$$

In this interaction model, every agent all has a state S_t and they can transit from one state to other state in this discrete environment. Markov policy may be expressed as (5):

$$\pi = (s_1, s_2, ..., s_t, ..., s_n) \quad (6)$$

The interactions between agent and environment are simulated synchronized finite automata. In this paper, we consider environment as a whole including inner and outer. Inner environment (S') is built by sensor fusion and learning. Therefore, in comprehensive integrated model under Fig. 2, there are two analysis models as follow:

Deliberative level:

$$f_d():S' \longrightarrow IS \quad (7)$$

IS Intelligent strategy

Reactive level:

$$fr():S \longrightarrow A \quad (8)$$

Coordination level:

$$f_c():IS \longrightarrow IB \longrightarrow A \quad (9)$$

The coordination level can transfer intelligent strategy to intelligent behaviors, and finally, they are broken down into the action sequence:

$$A = \left\{ a_1 a_2 a_3, a_4, ..., a_i a_{i+1} a_{i+2} \right\} \quad (10)$$

The action sequence still runs according to the POMDP model. We see from Fig. 2 that information (sensor and fuse information) is the driving force of the whole system. It can be seen from formula (9) that the symbolic processing and behaviorism can fuse organically. In addition, the structuralism (neural network) also adds to the design deliberative agents. The real-time is ensured by fr() and the level model expressed by (7), (8) and (9) run in parallel.

POMDP is different with the general MDP, and it can not rally get the system state. The uncertain dynamic system is modeled as the system of probability with discrete state.

If B is considered as the set of reliability status, the POMDP may transform the MDP. Then value function of POMDP is rewritten as (11):

$$V_t^*(b) = \max_{a\in A}\left[R'(b,a) + \gamma \sum_{b\in B} T'(b,a,b')V_{t-1}(b')\right] \qquad (11)$$

In which:

$$T^{\cdot}(b,a,b^{\cdot}) = P(b^{\cdot}|a,b) \qquad (12)$$

$$R(b,a) = \sum_{s\in s} b(s)R(s,a) \qquad (13)$$

But the complexity is exponential growing with state space (Lopez *et al.*, 2005), and it has slow convergence in a large state space. Therefore we must integrate other computing methods (fuzzy logical or GA) to solve this question.

Fusion of computing methods: In the comprehensive integrated model as Fig. 2, we may consider ISMR as a complex information system. From top-down, some soft computing methods (fuzzy logical, neural network and GA) based AI can be used easily, and from bottom-up, fuzzy logical and reinforcement learning not only ensure real-time but also realize complex behaviors.

It is not easy to deal with continuous state space, but fuzzy logic can make up for this defect. So we fuse fuzzy logic and reinforcement learning based on POMDP to design algorithm for reactive behaviors such as navigation, avoidance and goal-seeking.

From the perspective of the robot engineering, there are four computing model to guide people to design robotic system, which are concluded as process-oriented, object-oriented component-oriented and agent-oriented. The computing of agent-oriented follows a rigorous design process and is future direction of development. And it creates a decoupling between hardware and software, and it provides platform for engineering design in the same time.

Case study: Under this comprehensive integrated modeling approach and modeling methods, According to comprehensive integrated model as Fig. 2, our design steps are expressed as following to solve the two problems mentioned above from two angles including architecture and intelligence.

- Analysis the basic model on the basis of areas of need.
- Select agent to take place of basic model under Table 1.
- Abstract analysis model of system including selecting interaction algorithm accordingly.
- Construct integrated model under frame (Fig. 2)
- Design information processing mechanism on the whole based on MDP or POMDP.

To verify the effectiveness of this modeling method, we use two examples including known environment and unknown environment to illustrate the modeling process. The results of experiment have shown the feasibility of this modeling method.

Example 1: Intelligent handing service robot navigation The intelligent handing service robot usually works in known environment. And it can move on the predefined routes or dynamically routed trajectory automatically. In fact, it follows the predefined path to achieve autonomous navigation.

After analysis, we can see that the intelligent generation mechanism mainly is reflected in reactive layer under Fig. 2. There are relatively fixed routes constructed by magnetic tape, so the modeling based on fuzzy logical may achieve the system design. In this modeling, the policy π = f (). is addressed as fomular (14):

$$\Delta V = f\,(MRSr, MRSl) \qquad (14)$$

According to practical application, we get the look-up table Q((MRSr and MRSl)i, $\Delta.V_i$) and then the navigation agent is achieved successfully. The prototype test results are shown in Fig. 3. ΔV is the amount of differential drive control and MRB is the magnetic sensor.

Example 2: Design ISMR for gas-check:

The gas-check ISMR is used to check the toxic gas including Cl_2, NH_3 and combustive in chemical industry park through cruise. It can send local information of gas concentrations and image to control center by wireless network, and in the same time, it may interact with human through voice recognition. Its mobile motion includes two ways which are cruise through guides and Obstacle-avoiding by roaming. This intelligent system is so complex that it includes all levels in Fig. 2. Nevertheless, we still use the steps described above to analysis it.

As it involves more content, we discuss the problem how to fuse fuzzy logical and reinforcement learning in

Fig. 3: Experiment based on fuzzy logical

Fig. 4: Experiment based on fusion alogrithm

gas-check ISMR roaming. The roaming includes two intelligent behaviors (obstacle-avoiding and goal-seeking). In the process of designing navigation and Obstacle-avoiding we integrate the fuzzy logical and reinforcement learning to complete the task successfully. In practice, the robot uses infrared, ultrasound and GYR to navigation. According to the distance and angle to the obstacle, we discrete state of the environment and use fuzzy logical to represent the policy $\pi = f'(\,)$, and correct policy by RL based on POMDP. The experiment prototype is shown in Fig. 4.

CONCLUSION

On the basis of Metasynthesis, a new modeling method of ISMR is provided in this paper. For modeling intelligent robots, there are still no unified modeling methods. In particular, system analysis and design of agent-oriented is still being explored and controversial. In order to seek for methods of system analysis and design scientifically for ISMR, we discuss a new methodology from the macro (system architecture) and micro levels (basic model-agent). Full three-dimensional integrated model is contributed to understand information processing mechanism and intelligent organization, so as to understand intelligent system all-round. Under the metasynthesis architecture, the complex robotic system may perform by basic model and hybrid algorithms. The agent can not only integrate hardware and software, but also fuse intelligent generation mechanism or intelligent information process algorithms, which have provided good condition for design complex robotic system.

In this, study we want to seek for system analysis model for ISMR. From this analysis process and experiment, we endeavor to seek some common modeling methods of building intelligent robotic system. And in the course of this exploration, we are able to see that comprehensive integration is inevitable trend in designing intelligent robotic system.

Fuzzy logical navigation and its fusion with RL based on POMDP have explained that the hybrid based on soft computing and robotic learning is a great prospect in modeling robotic system. In addition, from the basic model and its analysis model, we also see that agent indeed have brought convenience for designing robotic system. Good features of agent will make it become a new computing model in the future. The comprehensive and integrated approach based on agent is important future research directions.

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REFERENCES

Brenna, A., C. Sonia, V. Manuela and B. Brett, 2009. A survey of robot learning from demonstration. Rob. Auto. Syst., 57: 469-483.

Brooks, R., 1986. A robust layered control system for a mobile robot. IEEE J. Rob. Auto., 2(1): 4-23.

Brooks, R. and M. Kaupp, 2007. ORCA: A componment model and repository. Software Engineering for Experiment Robotics, pp: 231-251.

Cao, L. and R. Dai, 2008. Fundamentals, Concepts, Analysis, Design and Implementation. Post and Telecom Press, Beijing, China.

Carmine, G., L. Lucio and L. Vincenzo, 2006. Agent-based architecture for designing hybrid control system. Inform. Sci., 176: 1103-1130.

Chella, A., C. Massimo and G. Salvatore., 2010. Agent-oriented software patterns for rapid and affordable robot programming. J. Syst. Software, 83(4): 557- 573.

Lopez M.E., L.M. Bergasa and R. Barea, 2005. A navigation system for assistant robots using visually augmented POMDPs. Auto. Robots, 19(1): 67-87.

Muciente. M., F.J. Alcala, R. Alcala and J. Casillas, 2010. A case study for learning behavior sin mobile robotics by evolutionary fuzzy systems. Expert Sys. Appl., 37: 1471-149.

Nethmzow, U., 2006. Scientific Methods in Mobile Robotics-quantitative Analysis of Agent Behavior. Springer-Verleg London limited.

Simon, H.A., 1981. The Sciences of the Artificial. 2nd Edn., La Cambridge, MIT press, MA.

Vasilyev, A., 2002. Synergetic approach in adaptive system. M.A. Thesis, Transport and Telecommunication institute, Riga, Latvia.

Xie, W., M. Jiachen and Y. Mingli, 2010a. Agent-oriented architecture for intelligent service robot. Proceedings of the 8th World Congress on Intelligent Control and Automation, pp: 5964-5967.

Xie, W., M. Jiachen and Y. Mingli, 2010b. Design of hybrid architecture for intelligent service mobile robot. Proceeding of International Conference on Electrical and Control Engineering, pp: 740-743