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Research on Building Mechanism of System for Intelligent Service Mobile Robot

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1. Introduction

With the development of computer, communication, automation and system integration technologies, advanced research in service mobile robot has made rapid process. The modern intelligent service mobile robot (ISMR), viewed as an every day life "partner", has entered a critical period of industrialization. It not only takes place of people to do dirty, dull and dangerous (3D) work, but also becomes people's friend and chummy assistant in the future. But how to design robot system scientifically and efficiently is a hot issue in robotics because the design of robotic system is often so complex that it is difficult to seek underlying problem-solving approach. The lack of integrated methods with reuse approaches leads robotic developers to reinvent the wheel each time a new project starts(Chella et al., 2010) .Until today, the methods for designing intelligent robot may be concluded two approaches which are "Trial and error "and "Repeated optimization" (Nehmzow, 2003). So many researches have begun to study in this area from both robotic science and engineering. To sum up, there are mainly two research ideas which are "seek for systematic and scientific methodology" and "seek for general system architecture" for striving to achieve "methods reuse" and "architecture reuse".

As for seeking for systematic and scientific methodology, there are many arguments in robotics. In the same time, there are two research thoughts for designing intelligent robot (Joseph et al., 2004), one is "top-down" which is based on symbolic processing; and the other is "bottom-up" which is based on principles from biology. Currently, the two research methods are coexisting and have comprehensive integration trend. Pfeier provided the synthetic methodology of "understanding by building"(Pfeier, 2005). They mainly include two views of "constructing a model-computer or robot" and "abstract general principles from the model". He had concluded some principles including emergence, diversity-compliance, time perspectives, frame-of-reference, three constituents, complete agent, parallel loosely coupled process, sensory-motor coordination, cheap design, redundancy, ecological balance and value for guiding people to design intelligent system. Yavuz had proposed a new conceptual approach to the design of hybrid control architecture for autonomous mobile robots (Yavuz, 2002). It took the advantages of various control structure and then integrated them using comprehensive methods. And then, he proposed an integrated approach to the conceptual design and development of an intelligent

autonomous mobile robot (Yavuz, 2007). A clearer view of the design approach based on function-oriented interdisciplinary were shown and the main functions of intelligent autonomous mobile robot were divided into Mobility, Navigation and Autonomy. Similarly, corresponding to design needs, five non-functional requirements including simple overall structure, cost effective, robust structure, intelligent and adaptive behaviour, and reliable operation were provided. Finally, those requirements were decomposed into smaller functions which could be performed by mechanical, electronic and software system through FD tree. In short, with the increased complexity of the system, the relationship between functional modules become more and more complex, so the overall system analysis and design still face many difficulties.

As for seeking for general architecture, many scholars tend to explore a common system reference model to reduce the duplication of design process. Architecture is the backbone of building complex intelligent systems (Ève coste-Manière, 2000). It can describe clearly that how the system is down into subsystem and how the subsystem achieves the overall function through the interaction of organic. Appropriate architecture make the robot system analysis become simple, so general architecture research has made some progress. For example, NASA and NBS's NASREM level reference model (Albus et al. 1989), Zeebo open architecture(Bogdan, 2006), ROACS(Real-time open-architecture control system) (Gu. J.s, 2004) and Daqing Wang's MRR (Modular and re-configurable robot) (Daqing wang, 2006), but they sill lack of effective methods of that how to analyze and design robotic system based on architecture systematically.

On the whole, in order to solve the difficult problems, we need to consider it from two aspects. One is the research of the scientific, systematic analysis methods, which is related to robotic development; and the other is the research of architecture, which is related to system model.

In essence, the robotic system is a complex information process system. But it is different from the computer, and its design must be considered together with the hardware and software. The systematic and comprehensive analysis of the intelligent service robot is still rare and not unified modelling methods and tools so far. Therefore, it is imperative to explore new methodological guidance for building mechanism. Our proposal tries to merge the strong points of the study methods mentioned above while minimizing their weak points, provide an open architecture for ISMR, and then explore the building mechanism of system for intelligent service mobile robot from metasynthesis's point of view.

The chapter is organized as follows. The features of analysis and design for ISMR are introduced in section 2. The metasynthesis of open architecture for ISMR is discussed in section 3. And the development model based on architecture is proposed in section 4. the system model based on Agent is provided in section 5. Finally, take a specific example to illustrate the efficiency and rationality of building mechanism in section 6. In addition, conclude and discuss this new methodological guidance of system analysis for ISMR and further research directions.

2. The features of system analysis and design for ISMR

2.1 The difference between robot and computer

Some people may ask, Robot system is ultimately embedded computer systems, we can use computer analysis methods to guide design robots, and compared to computer system, are

there other special aspects in robotic? Robot system and logical relationship between the flow of information structure is calculated on the basis of computer platform, but the robot design and computer design is different.Because of the design objectives and the special constraints, the robot design is more complex than the computer . To successfully design the robot system, we must first understand the difference between the robot and the computer(as shown in Table.1), and then absorb and inherit of the computer system scientific analysis methods.

Point of difference	Robot	Computer
Information stype of input	Changing stimuli information are provided by sensors	Discrete information are providesd by key or mouse
Environment identification	Robots themselves	Computer users
Run way	Produce intelligent behavior accoring to chance from environment	Compute the need results from each operation of program
Design verification	Have difference between simulation model and the actual	Good repeatability of Simulation model
Intelligent forms	Deliberative reasoning and behaviourism	Symbolic reasoning
Environmental adaptability	Adape dynamic and unkown environment	Adape kown environment only
Real-time	Require to response changes of environment quickly	Relatively weak

Table 1. Comparative analysis between robot and computer

Overall, the robot is similar to organisms, which has a large number of complex sensors, and provide information or stimuli by them to understand and identify the environment, after that produce intelligent behavior through intelligent information processing to form a comprehensive closed-loop system. So the robot system design, not only need computer knowledge to support, but also need expertise and experience in robotics. Therefore, The combination of scientific methodology to build a computer system, robot designed common design theory, principle or a combination of domain modeling mechanism, are important condition for effectively building robotic systems.

2.2 The features of ISMR

For the robot, it's applications and the environment are very complex and there are still no unified theory and tools, so compared with the computer system, the robot can not be isolated only from the system of symbolic reasoning mechanisms, and it should be integrated and designed form the impact of three factors including body, environment and the task. In fact, the process of analysis and design is an integrated system, which turn these three system domain model to information mechanism.

In the intelligent service robot system, the robot body, the environment and the task work together, determine the robot's intelligent behavior. Therefore, when we conduct system analysis and design, the main line through the design of information systems includes not

only general information processing mechanisms, but also intelligent simulation or generation mechanism.Different Intelligent generation mechanism corresponding to different intelligent information processing method.

To sum up, intelligent robot with the characteristics of the following seven aspects(Zhu miaoliang, 2001).

F1: "survival" in a real the objective environment

F2: has some intelligence (intelligent generation mechanism)

F3: autonomous (independent of the problem-solving)

F4: has some ability to learn

F5: complex structure, Full range of levels

F6: belong to hybrid intelligent systems

Compared with general robot, ISMR is developed with the aim to perform operations in special no-industrial tasks, so it has some new features as follows excepting above(Xie wei, 2010).

F7: intelligent demanding

F8:module versatility

F9:friendly human-robot interaction

F10:secure high-performance

As can be seen from the above characteristics, building intelligent mobile robot is a complex process of comprehensive integration. With a variety of subjects (control theory, operations research, developmental psychology and systems theory, etc.) of the theories and methods to the penetration of artificial intelligence, comprehensive and integrated approach is an effective way to analyze the design of intelligent mobile robot system. Summarizing the design of robotic systems in recent years, according to Mr. Qian Xuesen's comprehensive integrated methodology(Cao Longbin, Dai Ruwei, 2008), comprehensive and integrated strategy of the robot can be summarized as the top-down and bottom-up, system abstraction and simulation complementary, more angle comprehensive modeling approach, multi-disciplinary, human (qualitative) and robots (quantitative) combination, complementary non-functional and functional division and from qualitative analysis to quantitative modeling and integration analysis.

3. The open reference architecture of ISMR

If we want to build an intelligent robotic system, the first step is to determine the appropriate architecture. The architecture includes information processing and control system, which ensures reasonable coordination, openness, and scalability of robotic system. The same as the brain, the architecture is the platform "body" for realizing intelligent behaviours, so new developments in artificial intelligence can provide some new ideological for designing ISMR. Actually, robotic system design involves two aspects of engineering and science. If there is no systematic analysis and design, any design methods based on "repeated optimization" and "trial and error" are difficult to design the overall behaviour offline. In this section, the typical reference architecture in the past 30 years are classified and summed up systematically from system analysis perspective, and then some common principles for design architecture are concluded on the basis of previous classified research. Finally, the open reference architecture of ISMR is provided.

3.1 The classification of intelligent robotic architecture

People had provided much model architecture for intelligent robot system from different angles since early 1980's. The fact recognized by everyone is that three primitives including S (sensor), P (plan) and A (action) are the foundation of constructing architecture. S represents the ability to percept the internal and external state changes; P represents the ability to make decisions autonomously based on conditions, status and constraints; A represents the basic actions or behaviors of robot. According to this relationship between the three primitives, the structure of intelligent robotic system is classified three paradigms correspondingly including deliberative ($S \rightarrow P \rightarrow A$), reactive ($S \rightarrow A$) and hybrid (deliberative/reactive). Recently, the development of distributed artificial intelligence (DAI) had created new conditions for realizing hybrid paradigm. Parallelism, distribution, open and scalability will become new characteristics. Therefore, we divide previous reference architecture into categories which are traditional architecture and agent-based distributed architecture.

3.1.1 Traditional architecture

The traditional architecture is divided into three categories on the basis of three research paradigm (deliberative, reactive and hybrid). We sum up their characteristics from design thought, analysis methods, intelligent generation mechanism, and typical examples as shown in Table 2.

Category	Deliberitive	Reactive	Hybrid
Design thought	Simulate human thinking such as introspection and deliberative	Simulate organisms perception-action response mechanism	Intergration of deliberative, reactive advantages
Analysis methods	Top-down	Bottom -up	Metasynthesis
Intelligent generation mechanism	Symbol docytrine	Behaviorism	Comprehensive integration and connectionist
Typical examples	Shakey, NASREM, 4-D/RCS	Subsumption and reactive based on motor schema	3T, AuRA, TCA and Sahira

Table 2. The comparison of three research paradigm

3.1.2 Agent-based distributed hybrid architecture

Recently, more and more researches have introduced multi-agent system (MAS) to construct mobile robot system. Based on this theory, robot's frame looks like a network that is made of agent node. Agents are independent and of self-awareness, so the large-scale problems were expected to solve by this way. Therefore, in the module design, there are many researchers to replace modules with agent and the multi-agent system (MAS) mechanism based distributed control has provided a new train of though for designing ISMR. Now, more and more researchers use agent paradigm to solve complex problems. A multi-agent architecture for mobile robot control was provided by Kolp (Kolp 2006), he compared it to other classical structures such as control-loop, layered and task-trees and the results had shown that the

structure-in-5 and joint-venture based on MAS had obvious advantages. Grelle (Grelle 2007) used the agent paradigm to design very complex control strategy through multi-objective, fuzzy c-means, and genetic algorithms optimization. Under the hybrid architecture, the traditional control model was extended in agent-based distributed system. The classical architecture including the integration architecture of MAS and collaborative (Bianca, 2008), SC-agent architecture (Posadas, 2009) . Because the agent can decouple hardware and software, some methods of soft computer may be used to address cooperation and competition between agents. The approach of neural network based on evolutionary and reinforcement to design agent were presented in (Strnislav, 2010), and the results had shown Q learning algorithm was more adaptative for agent.

3.2 Discussion of common principles

Through classification and summary of past typical architecture, we not only can absorb previous experience and lessons, but also induct some common design principles for guiding follow-up study. Inspired by Pfeifer's new ideas of embodied cognition (Pfeifer, 2005), we can understand intelligence system by building. Historical experience have also proved that some new ideas or thought emerge from building a real physical system. Therefore, the general methodology on the basis of previous experiences and views are expected to get. And then, borrowing ideas from Pfeifer, we have concluded six common design principles for constructing architecture of intelligent robot system (Xie wei 2010).

- Principles of modular division based on S, P and A
- Hierarchical principle of architecture
- High cohesion and low coupling
- Design principle of redundancy
- Coordination principle between deliberative and reactive
- Principle of open-hardware based computer platform

Although the robot intelligence is so mysterious that people understand it only from a different side, we still can conclude some common design principles which are guidelines for designing efficiently robot system.

3.3 The open reference architecture of ISMR

From the development of architecture in last 30 years, we find that hybrid paradigm is effective design methods for constructing intelligent robot system. The computing models are the basis of robotic analysis and design, which have changed from process-oriented, objected-oriented and component-oriented to agent-oriented. And agent-oriented distributed hybrid architecture has more obvious advantages such as modularity, integration capability, scalability and openness than traditional architecture. But no matter which type of computing model is selected, it must have open reference architecture, only in this way, the design of ISMR is expected to change from code reuse, module reuse, component reuse to architecture reuse.

Combining six common principles above to metasynthesis, and referencing to common core mechanism of "information-Knowledge-intelligence converter", an open and space-oriented reference architecture of ISMR with learning mechanism is presented in this paper as shown in Fig.1.
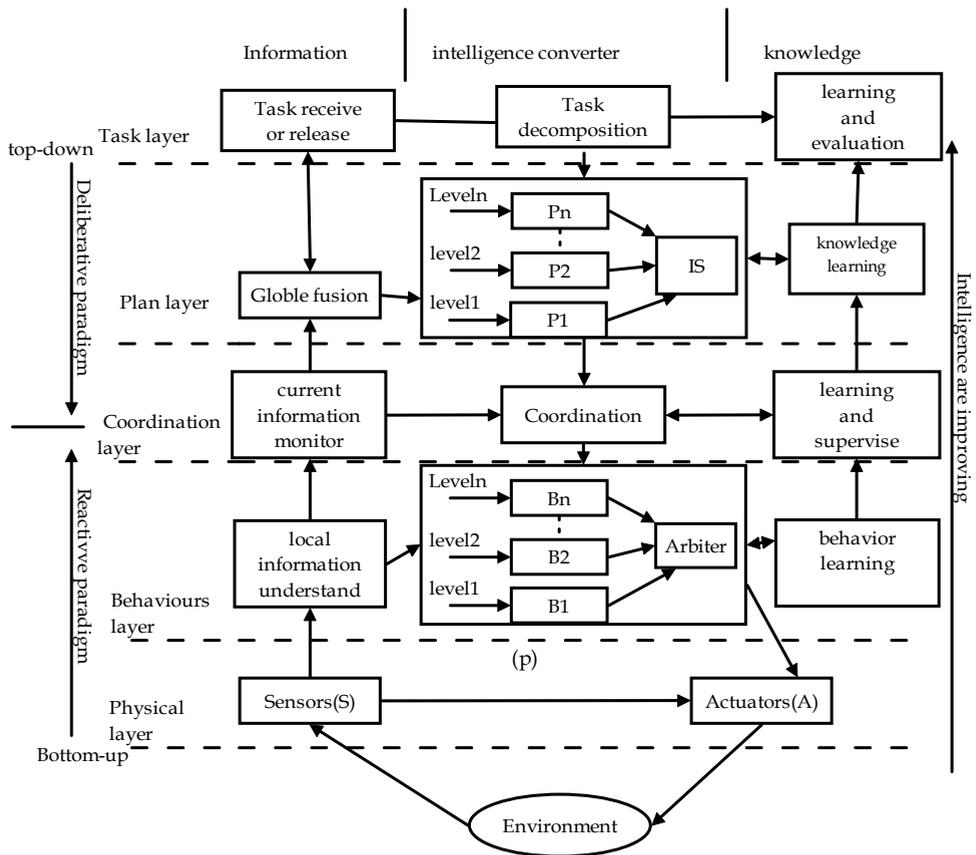
Fig. 1. The open and space-oriented reference architecture of ISMR with learning mechanism

As can be seen from Fig.1, in the space of the layered architecture, both vertical and horizontal dimensions are used to build the analytical framework. It is from the lower physical layer, behaviours layer, coordination layer, plan layer to task layer in vertical dimension, and from the left to right, it is divided into information, intelligence and knowledge conversion mechanism. The physical layer mainly includes sensors and actuators. And the openness is embodied in IS (intelligent strategy) and reactive intelligence based on successive hierarchical mechanism. Under this architecture, it is easy to form a comprehensive integrated system of division and interaction. From low to high, it shows the intelligent space hierarchy and intelligence are increased gradually. However, from the left to right, it reflects the intelligence produced by the common core mechanism. Therefore, this architecture has reflected the full range of intelligent frame structure of system content.

4. The development model of ISMR based on architecture

Each robot has its own architecture, like everyone has the body. Good architecture not only makes the problem easier to solve, but also is more conducive to the integration of complex subsystems. This is the purpose of our study architecture. The traditional design of robotic

systems' development life cycle is divided into problem areas and the determines of the objective function, system analysis, system design, system implementation and system testing five stages(Zhu Miaoliang 2001). As the complexity of robotic systems are increased, it is difficult in the requirements analysis phase of an overall understanding of the system, so the actual development requires repeated changes and additions, more coupled subsystems, more experience components, lower development efficiency. Once the changes in demand or changes in the field of environment, much places needed to be modified or redesigned. The architecture as the backbone of the system, can help us build from the system point of view of system modules and intelligent interaction between this organization. Therefore, the section integrates with complex systems integration strategy, based on the architecture of the software engineering analysis method (Zhang Youshen, 2004 Hejian, 2004), and proposes development model of intelligent robot system based on architecture as shown in Fig.2
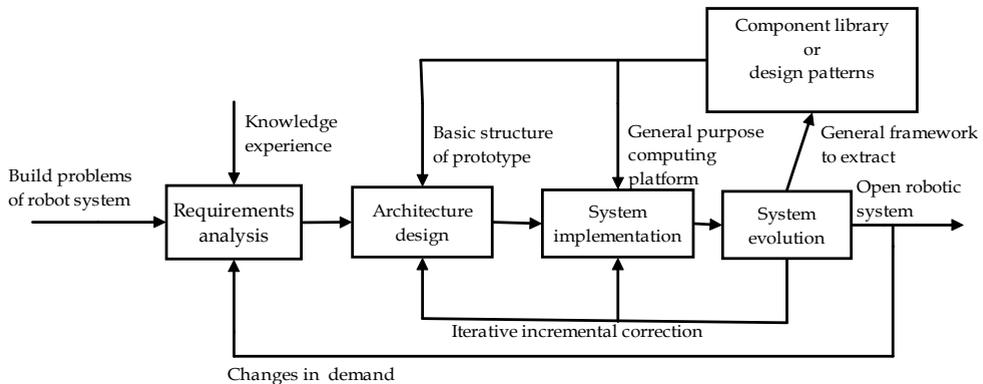

Fig. 2. Development model of intelligent robot system based on architecture

In Fig.2, the core is the architecture design. Architecture likes a bridge, which connect the robot system problem solving, needs analysis and information system. Inspired by the software architecture research ideas, the development model of Fig. 1 is divided into four design space, which are functional design (FD)space based on demand analysis, architecture design (AD) space based on architecture, system design (SD) space based on system implementation and system evolution (SE) space based on evolution(including testing, optimization and iterative modification), which are functional design (FD)space based on demand analysis, architecture design (AD) space based on architecture, system design (SD) space based on system implementation and system evolution (SE) space based on evolution(including testing, optimization and iterative modification), and finally the open robotic system are formed and some design models or components are built, then the development life cycle is completed. Compared to traditional system development model, it not only reflects the comprehensive and integrated methodology from the qualitative to quantitative, but also makes the system design from code reuse, reuse components to reusable design patterns, and improve the system development efficiency.

4.1 Requirements analysis
Robotic system requirements analysis include three aspects which are the problem description and classification (solve problems), determine the scope (constraints) and design

goals (performance indicators). Has been proved(Hejian, 2004), 70% of software errors are that the result of requirements analysis is not clear, so pre- requirements analysis for the problem-solving and building system are critical. Description of the problem refers to analyze problems needed to slove clearly. Define the scope of the real refers to determine the system's objects and the environment. Only on the basis of two points of rigorous analysis in front, we determine the appropriate performance indicators. This is the same as the concept of three elements of the principle of "niche" (Pfeifer, 2005) . That is to say, on the basis of the expected behavior of the robot, we define the living environment of the robot, or applications. Such as service robots and industrial robots, 'niche' have different requirements, service robots are mainly used in homes, hotels and other more services social environment, but industrial robots are used in specific occasions such as factory environment which only need relatively simple interactions.

It can be seen from Fig.2, for demand analysis, there are two important external factors, including qualitative experience and knowledge or some common principle which are integrated into the design requirements analysis and combined qualitative design and specific areas of application requirements analysis together to solve human-computer collaborative problem. In the problem solving process, how to divide the problem is the key problem. Function-oriented classification method are easy to decouple hardware and software, and easy to analogy organisms, so it is generally recognized by every one. This method considers in conjunction with hardware and software to simplify system integration difficulties. But in the practice, the design of building robot system also face a number of non-functional requirements such as cost, robustness, operability and openness. When the three important aspects of requirements analysis is clear, we can use the existing experience or knowledge to identify problem-solving approach. When the results of the requirements analysis are converted into a functional description (the main function of the robot needs to be done) and non-functional description (constraints and performance indicators), we can see that requirements analysis is multidimensional. In the process of requirements analysis, regardless of how complex the problem to be solved, the problem can be driven in the framework of a causal relationship between the division. From different angles, this section provides three sets of functional design space for robot system (FD) to visually describe the needs analysis results.

$$FD = \{Fr, NFr, Ds\} \tag{1}$$

In which: $Fr = \{F1, F2, ..., Fn\}$ Functional requirements set

n is a natural number

$NFr = \{NF1, NF2, ..., NFn\}$ Collection of non-functional requirements

$DS = \{Ds1, Ds2, ..., Dsn\}$ Set of design specifications

For example, in this analysis mode, Hakan Yavuz's intelligent autonomous mobile robot system functional requirements are expressed as a set:

$$Fr = \{Mobility, Navigation, Autonomy\} .$$

Of course, the requirements analysis is not static, on the one hand, before the next system design it should assessed and changed repeatedly, and then be formed to documented description normative; on the hand other, after systems construction is built completely and

fulfilled, changes are caused by increasing or reducing part of the functional and non-functional requirements. So the analysis needs to consider the dynamic update mechanism. These two external factors form requirements analysis process of comprehensive and integrated robotic system.

4.2 The design of architecture

According to IEEE610.12-1990 for the definition of software architecture: "Architecture is a system basic structure which contents component, the relationship among the components, the relationship between component and environment and a principle of guiding the design and evolution of the content above. " It can be seen that, components, connectors, environment and principle are of its constituent elements. At present there are not formed accepted general definition, but "Software Architecture = {components, connectors, constraints}" is generally reach a consensus. In the robot system, reference to the definition of software architecture studied by Bass, Shaw, Boehm and so on, the architecture can be understood as an abstract system specification, mainly used to describe interconnect and the set of various functional components, also includes guiding design principle. In the system development model based on robot architecture, the main task of designing architecture is to design the content based on function, to make out the content or basic structure and achieve these content and the relationship between them clearly, to make out system analysis model, to form the structure of the system design space (AD).

4.2.1 The abstract of system component

Robot academic generally accepted that, functions of robot are divided into three categories: sense (S), plan (P) and achievement (A).From the existing literature, it has not find more universal significance than these three functional classification, meanwhile S, P and A was also seen as the three primitives of building a robot system. Although the learning (L) to build intelligent systems as a primitive is still debated, in this section, we consider the learning paradigm as the fourth one apply to the design of the system, because learning is the most important manifestation of intelligence and integrated in the first three primitives. According to "By constructing to understand intelligent systems" and the relationship between these types of research paradigms, the robot basic system, combining to intelligent organization, is abstracted as three species: deliberate, reaction and hybrid (deliberate/reaction), corresponding to the three basic architecture. The characteristics of these three basic architectures are shown in Table 2. According to these research ideas, the components can be replaced by these four primitives. Intelligent organization form and architecture design of system are united and then to the component model of building intelligent systems are achieved.

Throughout development of research on intelligent abstraction mechanisms recent years, it experienced from the symbolic intelligence (the physical symbol hypothesis as the representative), connected intelligence (the artificial neurons as the representative), on-site intelligence (perception - action mechanism as the representative) to the community smart (Agent, represented in the social interaction, organization and emergence, etc.). As can be seen from Table 2, the basic architecture design and intelligent abstraction mechanism are integrated to consider.

4.2.2 Basic architecture analysis model

System modeling is the core of the architecture, the environment and the objects intelligent mobile robot systems to deal with are very complex, there is no unified theory and tools.

Building abstract and appropriate model help us to analyze the integrated mechanism and intelligence generation mechanism of architecture. It's easy to do dynamic optimized analysis, and also to predict the results of running in the environment. Recent cognitive structure, neurological psychological structure and architecture based on learning and emotion all can be regarded as evolutions of these three basic architectures. Therefore, if we consider the basic architecture as the study prototype, the system model is easy to discussed.

From a macro point of view, the level of robot intelligent will be reflected by intelligent behavior finally. While the most important factor of affecting intelligent behaviour is the sense of the environment (S), so if we take IB (intelligent behavior) as output, the environment as input, then the basic architecture of a simplified model is expressed as:

$$f : E \rightarrow IB \tag{2}$$

Among them, f means mapping mechanism from environment to intelligent behaviour. In the intelligent service robot system, the environmental status information are divided into two categories: external and internal environment. External environment includes robot running ecological environment and task information released by human or other robot; internal environment includes information about robot's understanding of environment (global and local) and introspection information (dynamic cognitive knowledge, learning, evaluation, memory information, etc.). Intelligence mainly is showed as intelligent strategy selection and the generation of correct behavior. In different environment, the mapping mechanism f is different. So based on functional design space requirements and the basic architecture, intelligent robotic systems analysis model will be built. System architecture design space (AD) can be expressed as a set:

$$AD = \{A_1, \ A_2, \ A_3, ..., A_n\} \tag{3}$$

A_i means the basic structure of subsystem

According to this conversion from function design space to structure space, how to make mapping mechanism? This mapping mechanism must be met the real-time requirements by relatively simple linear transformation (including general and special) or fuzzy query table. Linear transformation method describes model f by a linear mathematical model or ARMAX(Nehmzow, 2006)system identification method. Method of fuzzy query table $Q(s, a)$ achieves nonlinear f mapping mechanism through off-line fuzzy logic, and complex behavior will be real-time and dynamic completed, looking up table online. This analysis based on bottom-up and interaction principle based on perception-reaction have laid the foundation for the realization of reactive intelligent behavior. It is noteworthy that, in the lowest level of response mode, closed-loop control system as chief, such as motion control system, has the strongest instantaneity, can also be attributed to the special analysis model: $S \rightarrow A$. The mapping mechanism is designed with control system design theory.

Deliberative style basic architecture ($S \rightarrow P \rightarrow A$), is came true through intelligent information processing mechanism (mapping or policy). Planning includes task decomposition, scheduling decisions, global and local path planning. Online and off-line planning are coexistence. On-line planning includes environmental awareness, sensor fusion, task decomposition and scheduling, cooperative control and real-time path planning;

off-line planning includes building a library of knowledge and experience, the identification of demonstration representation and trajectory planning. The generation of intelligent strategies come from planning. Driven by goals or tasks, the sensor information are fused and processed into knowledge, intelligent strategies are self-generated and then intelligent behaviours are expected. The traditional deliberative design focuses on logical reasoning-search. In recent years, some soft calculation methods (such as fuzzy logic, neural networks, evolutionary computation, etc.) are applied to the deliberative reasoning design which reflect the comprehensive integration trend. For example, ANN hybrid architecture (Xu Yu-ru, 2007) used by XU Yu-ru combined with symbolic reasoning and artificial neural network, fully embodied the strengths of complementary of fusion.

Of course, if you reuse the basic architecture, then the corresponding mapping mechanism can be reused. This gives convenience to system analysis and design. For example, obstacle avoidance and along the wall of the differential behavior robot studied by Joseph (Jones, J.L. 2004), the same type of obstacle avoidance sensors are equipped on robot's left and right sides. He took mapping mechanism as common linear transformation model A , provided us with general ideas based on behavior analysis model. Simply select the appropriate transformation matrix A , reactive intelligent behavior can be achieved.

Intelligent behavior IB matrix expressed as:

$$IB = \begin{bmatrix} Tr & R & Tri \end{bmatrix} \tag{4}$$

Tr : Translation speed; R : Rotation speed; Tri : Trigger flag

Assuming the sensor input El and Er , The matrix is expressed as:

$$E = \begin{bmatrix} El & Er & 1 \end{bmatrix} \tag{5}$$

Status signal: 1 indicates that this behavior is triggered, 0 indicates that this behavior is not triggered

Then there exists a common linear transformation matrix T .Such that $IB = ET$.

In its light-seeking robot design, if $Tr = V$, V means speed navigation; $R = K(El - Er)$, K for the normalization factor, the corresponding linear transformation matrix is:

$$T = \begin{bmatrix} 0 & K & 0 \\ 0 & -K & 0 \\ V & 0 & 1 \end{bmatrix} \tag{6}$$

4.2.3 Architecture of the spatial distribution

Currently, the concept that intelligent system should be layered has been widely recognized by everyone. The four-model computer systems and the seven-model computer network architecture, fully reflects the level of modeling ideas. Intelligent robot system with multi-level, three-dimensional and flexible, dynamic organizational structure and other features, are the same as cognitive scientists believe that animals have different levels of spatial capacity (reflection, integration, learning and cognitive). Therefore, the simulated biological process of intelligent systems also run through this philosophy. For example, the hierarchical structure of Saridis, level from low to high and intelligent increasing, the control

precision is decreasing. The subsumption structure of Brooks, with that the high-level tolerant and include the low-level behavior and have the characteristics of stacked layers, this hierarchy has provided a convenient for building robotic system. In this framework, or the distribution of each layer, the component form of organization may be divided into centralized, distributed and hybrid (centralized/ distributed). The intelligence are increasing with the level of compatibility, from low to high. The comparison of three kinds of organization for designing system in Fig.1 are described in Table 3.

Category	Centralized	Distributed	Hybrid
Describe Ci is component			
Scheduling	C0 plans and schedulings global information	Every component has local information	Balance the first two
Advantages	Facilitate unified planning and management	Distributed management and Heterogeneous components can be integrated	Metasynthesis
Disadvatages	Single information flow and weak rebustness	Difficult to deal with global information and need collaboration and competition	Design complexity and diffcult to integrate
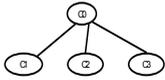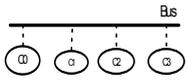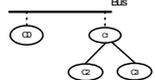
Table 3. Comparison of three organized manner based on component

4.2.4 The comprehensive integration of structure space

In the process of function design space are converted into the structure designing space, the functional set is converted into the basic architecture by the primitive. Then the non-functional requirements and performance indicators are reflected in the architecture of the constraints. If we use these components to achieve the function of Fr set, the connection between components and the algorithm can reflect the constraints of Ds and NFr set. Thus, according to functional and non functional requirements, we determine the basic structure of the analysis model, and select appropriate mapping mechanism to realize, and achieve a function designing space completely transforms into a subset of structure designing space (basic structure). Then the problems are transformed into that how to use these form the basic structure of the whole system model.

From the view of system theory, complex systems have a Character of "hierarchy" and typically have a structure of modular, so we use the method of hierarchical – aggregation and block-integrate modeling to solve this problem. Nearly 30 years analysis research of robot architecture shows that hybrid architecture is still dominant when the basic model and its organization are identified, we use the comprehensive integrated spatial structure of intelligent service as Fig.1 to build system gradually.

The robotic system building process are descried simply as following after the AD set of structure design space is determined, we can use the method of combination modeling to

integrate $AD = \{A_1, A_2, A_3, ..., A_n\}$ as the spatial structure under the frame in Fig.1. Each A_i represents a basic architecture, including components, connectors and constraints, which are used to form the overall system model. In this modelling process, according to the constraints, used the basic modular architecture, based on deliberative and reactive paradigms and different three-dimensional spatial structure of the 5-layer classification method, the association model is established, and then the various subsystems are comprehensive integrated organically. Finally, the overall model are formed. Since the independence of each layer, it enables the level of the surface to be extended independently. Combined with bottom-up, coordination ensures the deliberation and reaction layer to perform in parallel, thus, the openness and real-time have greatly improved.

4.2.5 Architecture assessment

The specific evaluation of architecture mainly comes from the constraints of FD. After FD are transformed into AD, these constraints were implicated in the design of architecture. Architecture evaluation requires a certain standard. Kolp(Kolp, 2006), based on research in Akin, derived from four qualitative evaluation criterias : support for modular, well-targeted features, easy to transplant to other areas and robustness. Anders Oreback (Anders, 2003) comprehensively evaluates the architecture of the mobile robot from aspects of hardware abstraction, scalability, uptime, software features, the implementing agency control modeling, tools, methods, documentation and others. Kolp put forward four qualitative evaluation standards from the perspective of organization theory: coherence, predictability, fault tolerance and adaptability, emphasis on evaluation of software systems . Drawing on these assessment criteria, particularly on the base of Anders Oreback, and the architecture design and analysis phase, we propose eight quality attributes to qualitatively assess the architecture design's reasonabilityas shown in Table 4. The architecture trade off analysis method(ATAM) is used to assess the architecture overall.

No	Quality attributes	Describe
1	Niche targetability	Functional integrity of the design space and consistency to architecture mapping
2	Modularity	Support modular, tight cohesion and loose coupling
3	Openess	Scalability, portability and reconfigurability
4	Adapt to the environment	Have adapt to the unkown and dynamic environment
5	robustness	Anti-interference ability and measures
6	Real-time response capacity	Real-time response
7	Security	Meet the three principles of Asimov
8	Document	Well detailed decumants

Table 4. Quality attributes of architecture structure assessment

4.3 System implementation

When the structure of the architecture design space is established, we form the specific system design space (SD), according to the whole comprehensive integration of assessed architecture. On this basis, we choose a suitable computing platform designed to achieve specific functions, and then to form the model for engineering system design. System

designing model includes the selections of computing platform and computational model. Therefore, the system design space is expressed as a collection of

SD = {computing platform, computing mode}.

Robot system is an information processing system in essence, whether deliberative plan or the acts reactive of synthesis, ultimately it comes down to a collection of computer-based hardware and software platform. Therefore, at this stage, we can use computer software engineering approach to modeling and analysis.

The difference between system design and architecture model is that the step of the former faces up with implementation and its main indicators are achievability and operability.We must firstly analyze quantitatively design specifications according to AD space including functional requirements and non-functional requirements from FD. Depending on the selected computer platform, we identified to achieve the basic architecture structure of the software modules (algorithms) and hardware modules (sensors, actuators and computing platforms), scope and interaction protocol between modules. In the design of architecture, when hardware module division has been very clear, we can determine the technology solutions of the hardware, according to the algorithm complexity of basic architecture model and the spatial and temporal distribution of the whole architecture. Next, the solution of the core issue is to choose the appropriate mode of computing, and use the appropriate tools to analyze and design a specific algorithm, so as to achieve comprehensive integrated modelling from different modular granularity. According to this idea, the design process of robotic system is converted into the next software engineering design problems for specific applications.

To sum up, the robot software design, there are four key application computing models: process-oriented (Process-oriented) approach, object-oriented (Object-oriented) approach for the component (Component-oriented) methods and agent-oriented (Agent-oriented) approach. In order to select the appropriate computing model, we conduct a comparative analysis from six areas, as shown in Table 5.

Category	Process-oriented	Object-oriented	Component-oriented	Agent-oriented
Basic unit	Sub program	object	component	agent
Computer process	Function call	Message, response	Message, response	Message, response
Abstrct element	Function	Object, class, modular	Component	Include organization, actor, target etc. excepting object and component
Granularity	small	smller	thicker	thick
Model tools	Flow chart	UML, ROSE, Usecase Diagram etc.	COM/DCOM Java Bean CORBA	AML, AUML, Gaia etc.
Typical applications	MCU, DSP program, etc	PC, ARM program and ROS design	Design of ditributed system based on WEB	Construction of complex intelligent system

Table 5. Comparison of computing model

On the view of the application of the robot engineering, these four computing modes are co-existence in the system design. We select the appropriate calculation patterns according to the algorithm, organizational structure identified in the system model and spatial distribution of the system. Then design the sub-module and the sub-system and determine the software development environment, following the corresponding modeling tools. So it is easy to build robot system software architecture. In addition, when we have completed the transition from system architecture space mode to system design space mode, we can test and evolve the algorithm of structure designing space through the simulation space or combination of hardware. modify the architecture design model by iterative incremental ways, until it meets system-related design specifications, finially establish a table or graph form the detailed system design documentation.

4.4 System evolution

Robot systems analysis and design is a dynamic iterative process. In the life cycle of systems analysis and design, the need of users and application areas of the environment may all change. Therefore, in architecture design, we need to consider the openness and scalability of architecture, in order to create conditions for the evolution of the system. Following successful tests, the system will extract some of the common framework to form the evolution of the design space (SE). If the system needs change, we must first update the functional design space, then search the evolution space (SE) that if there are ready component, and select add or reuse an existing structure, to achieve this function to find the basic architecture, in order to build a system design model. Accordingly, if the system tests have problems, we can date back to FD design space via the elements of SD design space. In the systems analysis and design of the architecture-based design and development model, system evolution is divided into two main lines. The first one is done to the structure design space from the functional design space, and done to system design space from the design space. Another is the change in demand, the use of the basic architecture and components extracted from homogeneous to update (add or delete) AD and SD elements. The dynamic evolution of the model shown in Fig. 3, this figure showing the relationship between the four design space.

When we decompose the robot system development process model into FD, AD, SD, SE four design space, we can use the collection analysis methods of robotic systems to get the qualitative and quantitative information. Here, we introduce a collection of characteristic functions, in order to complete the conversion of the four design space and structural modeling.
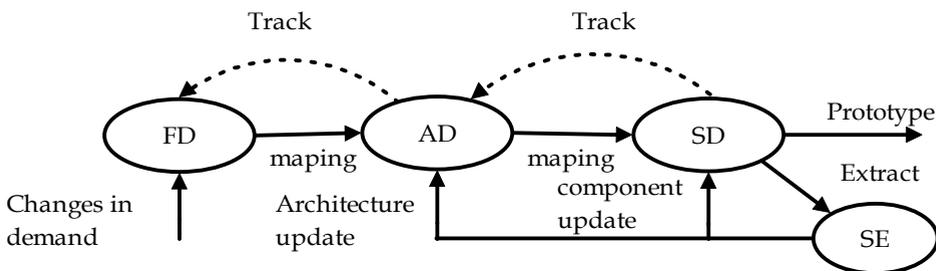

Fig. 3. Models the dynamic evolution of the system

Based on the U of A is a subset of the function:

$$\mu_A(x) = \begin{cases} 1 & x \in A \\ 0 & x \notin A \end{cases} \tag{7}$$

Set A is called the characteristic function. According to the nature of the characteristic function, the development model can be represented by equation (8) to. For any $x_i \in FD$, $y_i \in AD$, $z_i \in SD$ and, $k_i \in SE$, $i = 1,2,3,...,n$, present f', $f' : FD \rightarrow AD \rightarrow SD$, satisfies the equation:

$$\begin{cases} \mu_{FD}(x_i)\mu_{AD}(y_i)\mu_{SD}(z_i) = 1 \\ \mu_{SE}(k_j) \le \mu_{SD}(z_i) \end{cases} \tag{8}$$

5. Case study

Let us take a specific example to illustrate theory above. The intelligent gas-check service mobile robot (IGSMR) is used to check toxic gas autonomously through roaming or default route in chemical industry zone. And it can cooperate with human and help people detect gas leakage. Under the open and space-oriented reference architecture of ISMR with learning mechanism, according to the development model of ISMR based on architecture, the building process of IGSMR is divided into the design of FD, AD, SD and SE. And the design steps can be described as following.

1. Design functional space according to requirement analysis and ouput FD set.
2. Design the basic aechitecture analysis model accoring to FD set, and then integrate comprehensively the architecture space, output system reference architecture and AD set.
3. Select approprite computing model according AD set and Table 3, and then form system design model, finally output SD set and cooresponding physical implementation model.
4. Evolve (interative incremental correction) in the light of Fig.3 and test system, if it does not meet the requirements, return 1), otherwise, extract common components to SE.
5. Output detailed and standard documents after finishing the first four steps.

Fig. 4. Mulan No.1

Fig. 5. Mulan No.2

Subset of AD	Basic architecture	Environment sensor(E)	Intelligent Behaviors(IB)	Mapping Mechanism(f)
A$_1$	Reactive	Code/decode	Differential drive	PID
A$_2$	Reactive	Infrared	Obstacle avoidance	Generalized linear transformation
A$_3$	Deliberative	Magnetic sensor	Navigation	Fuzzy logic
A$_4$	Reactive	Ultrasound	Own roaming	Fuzzy logic and Reinforcement learning
A$_5$	Deliberative	Network signal	Runing state control	Generalized linear transformation
A$_6$	Deliberative	Power check	Independent charge	Fuzzy logic
A$_7$	Reactive	State detection within environment	Status indication	linear transformation
A$_8$	Deliberative	Sound	Sound identification	Fuzzy logic and leaining on-line
A$_9$	Deliberative	Photosensitive	Image processing	Soft computing
A$_{10}$	Deliberative	Gas-check sensors	Alarm or pre-process	Generalized linear transformation

Table 6. Architecture design space of IGSMR

From this design process, we can see that the design steps above are easy realized by computer. Because of space restrictions of this article, we manily focus on the architecture design of space. The architecture design is the core of buidling IGSMR, and the core of basic architecture is the mapping mechanism. If we grasp the core mechanism, we build robot ic system easily according to Fig.1. The physicals of IGSMR with navigation(Mulan No.1) and own roaming (Mulan No.2) are shown such as Fig.4 and Fig.5.

6. Conclusion

In this article, we have presented a new building mechanism of system for intelligent service mobile robot employed to address the robot system analysis and design problems. On the basis of previous studies, we provide firstly an open and space-oriented reference architecture of ISMR with learning mechanism, and then learning from software research methods, we present the development model of intelligent service robot system based on architecture which provide some engineering principles and theory foundation for building robot system effectively.

The design processes of ISMR are divided into four dynamic design spaces (FD, AD, SD and SE) which are contributed to integrate comprehensively. In addition, the three-dimensional spatial structure and how to design it, and formal theoretical model based on set analysis is provided. Compared to methods of conceptual design and integration (Yavuz, 2007), the methods in this paper have some obvious merits including intuitive, level clear, detailed size classification and easy computer-aided analysis, etc. From the case study of IGSMR, we conclude that this strategy not only have clear organization of intelligence, but also have high scalability and efficiency compared with traditional design methods. During the process of developing IGSMR, we use this method based on architecture to make overall efficiency increased by 40%. Moreover, the methods of analysis and design for ISMR have provided a new thought for architecture optimization and reuse of intelligent robotic system.

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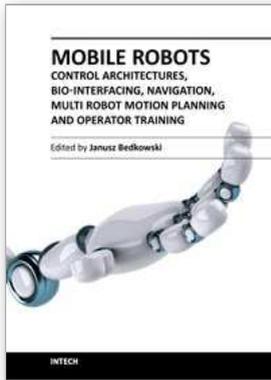
Mobile Robots - Control Architectures, Bio-Interfacing, Navigation, Multi Robot Motion Planning and Operator Training
Edited by Dr. Janusz Będkowski

The objective of this book is to cover advances of mobile robotics and related technologies applied for multi robot systems' design and development. Design of control system is a complex issue, requiring the application of information technologies to link the robots into a single network. Human robot interface becomes a demanding task, especially when we try to use sophisticated methods for brain signal processing. Generated electrophysiological signals can be used to command different devices, such as cars, wheelchair or even video games. A number of developments in navigation and path planning, including parallel programming, can be observed. Cooperative path planning, formation control of multi robotic agents, communication and distance measurement between agents are shown. Training of the mobile robot operators is very difficult task also because of several factors related to different task execution. The presented improvement is related to environment model generation based on autonomous mobile robot observations.

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