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SociBuilder: A Novel Task-oriented Swarm Robotic System

Yuquan Leng, *Member, IEEE*, Yang Zhang, *Member, IEEE*, Wei Zhang, *Member, IEEE*, Xu He, *Member,IEEE*, Dekun Bian, Weijia Zhou

***Abstract*—This paper presents a novel concept of swarm robots, which mostly emphasizes on organization structure, rather than merely the quantity. A novel task-oriented swarmrobotic system (SociBuilder system) that is self-reconfigurable and supports self-assembly is introduced. The system simulates human labor division and social organization structure, thus it could represent human construction activities. SociBuilder System mainly consists of four parts: active region, socibots, warehouses and modules. Moreover, we propose a novel swarm system hierarchy, which includes three layers: human-computer interaction (HCI) layer, task planning layer and execution layer. In the planning layer, we designe eight parts to actualize task-oriented mechanism, which are visual task analysis, task decomposition, task allocation, self-organization structure, action planning, expansion mechanism, sensor data analysis and derated analysis respectively. Besides, we displayed structures of Socibots and docking mechanism for self-assembly and self-reconfiguration in detail. Finally, three scenario simulations are implemented successfully including self-assembly task, cooperative task and building task.**

I. Introduction

The development of robots experienced three periods：1) Individual robotics (since 1950s); 2) Multi-robotics (since 1980s) and 3) Swarm robotics (since 1990s). In recent years, interest of swarm robots has been greatly increased, mainly for the following advantages: 1) Robustness; 2) Scalability; 3) Flexibility; 4) Economy [1, 2].

Swarm robotics occurs from artificial swarm intelligence, the biological studies of insects, ants and other fields in nature, so swarm robotics is defined as a new approach to the coordination of multi-robot systems which consist of large numbers of simple physical robots. It is supposed that a desired collective behavior emerges from the interactions between the robots or between the robots and environment [1, 2]. But a fuzzy key word in the concept is the definite number that “large number” means. Besides, the concept of swarm robotics should be extended with the development of robots. In this paper, we considered that the core of concept should focus on the characteristic of organization structure, not on how many robots which just make it like swarm robotics, so we propose that:

Swarm robotic system is a robotic system with a special organization structure, which is characterized by its considerable flexibility, unforeseeably changes in its scale even to an infinite number of individuals, and the wide range of individual structures or forms as long as they can interact with others or environments.

We believe that swarm robotics originates from multi-robotic systems, but the flexibility, unpredictability and mechanism of infinite plus or minus make it different. In multi-robot systems, scientists paid more attention to multi-robot cooperation, while in swarm robotics we need to focus on self-organization.

Robots are generated for solving task. That is “no task no robots”. Task is completed by a series of action, and which means robots interact with environment or objects[3]. Compared with process-oriented robotics system, Task-oriented robotic system is defined that system only cares for task schedule and result under the prescript constraints, not for how to do it.It needs autonomy, which assist the system to complete task decomposition, task allocation, self-organizations, action planning and etc [4]. The advantages of task-oriented robotics system are as following: a) Reduce technical requirements for operators; b) Improve the execution efficiency; c) Easy to cooperate; d) Enhance protection of mechanism in dangerous environment, and so on [4-6].

In the past decade, a series of isomorphic platforms have been built to imitate the biological motion behaviors, such as Pheromone Robotics [7], Kilobot [8], I-Swarm [9] and E-puck. However, we hope deeply those swarm robotics are able to operate objects for changing environment, so Swarm-bots [10] and TERMES [11] are researched. TERMES imitates the behavior of termites to establish building using special blocks. Swarm-bots is capable of realizing cooperative transportation, task allocation, self-reconfiguration etc. (Heterogeneous swarm robotics, such as Swarmanoid [12], is shown to imitate between different functional robots and simulate complex human behaviors It is comprised of numerous autonomous robots of three types: eye-bots, hand-bots, and foot-bots, and has been able to take a book from the shelf successfully. To actualize more complex task with space and temporal logic and researching dynamic organization among swarm units, we proposed a proper task-building task, considering that construction is a typical representative of human group

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Yuquan Leng, Yang Zhang, Wei Zhang, Xu He , Weijia Zhou are with the State Key Laboratory of Robotics, Shenyang Institute of Automation, University of Chinese Academy of Science, Shenyang, LN 110016 China (Corresponding author, phone: +86-24-2397 0466; fax: +86-24-2397 0552; e-mail: {lengyuquan, zhangyang, zhangwei, hexu, zwj}@sia.cn).

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activities. In this paper, we displayed a new novel swarm robotics system named SociBuilder system, which is a task-oriented swarm robotic system with strong ability of automatic planning, and is able to collaborate, self-reconfigure, realize building task etc automatically.

The paper is organized as follows. In section II, principle and overall structural design of SociBuilder system is discussed. In section III, architecture design of SociBuilder system is introduced. In section IV, two types of performers of SociBuilder system are described. In section V, some experiments on SociBuilder system are done including collaboration, reconfiguration and building task. Conclusions and future work are given in the last section.

II. System Principle

There are two products playing important role in human history. One is hierarchical social structure, which made every individual belong to one local organization with one leader. Another one is operation of the economy, which urged individuals to keep activity and helped appropriate individuals achieve opportunities and benefits. In order to represent those scenarios, we select building procedure as the core task to describe our system. SociBuilder is generated by the combination of two words: Social and Builder, which means every individual has social attributes and construction.

A. Elements of system

The implemented platform, as shown in Fig.1, includes four parts: Active Region (subdivided into task area, transport area, warehouse area A and B), Socibots (subdivided into Transbots and Handbots), modules (subdivided into Squ-modules and Rof-modules) and warehouse.

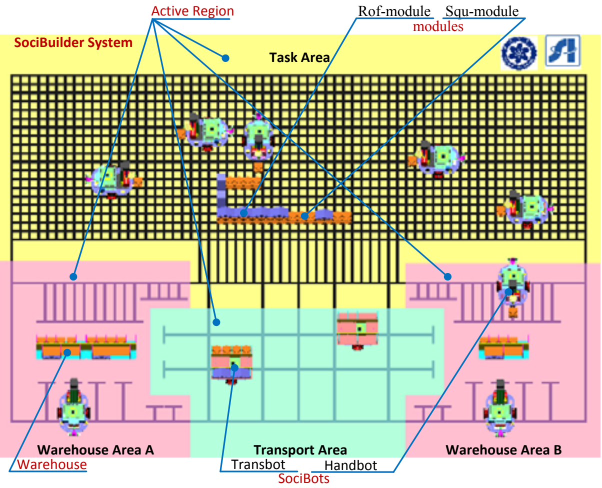


Fig.1 SociBuilder System

a) Active region

The area for Socisbots movement is called Active region, which contains many black cross lines. The distribution of lines can be changed relying on users' requirements, which assists Socibots to locate their position and planning movement. In this paper, active region is designed as shown in Fig.1, which includes four districts: task area, transport area, warehouse area A and warehouse area B.

b) Socibots

The Socibots are responsible for transporting modules or building house, which contain two types of individuals: Transbots and Handbots. Transbots are responsible for transporting modules from one place to another, which is the most capable of loading 4 Squ-modules and 2 Rof-modules. Handbots are in charge of building house, loading and unloading modules to Transbots, which is able to lift 400g objects. The detailed designs of individuals are shown in section IV.

c) Modules

Modules are building materials, which contain two types: Squ-modules and Rof-modules. The structure of Squ-module is shown in Fig.2, which is used to build house body. In order to easily assemble, Squ-module is designed with four quarter circular legs and four quarter circular holes. Two waist-shaped holes are processed in four sides for operating and constructing more kinds of house shape easily. Besides, black mark square is set on the top assisting operation using visual for Handbots.

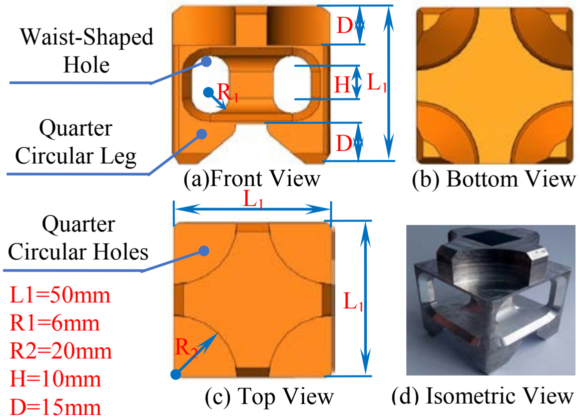


Fig.2 Structure of Squ-module

The structure of Rof-module is shown in Fig.3, which is used to build roof on two Squ-modules. Many structure sizes are same with Squ-modules for unity. In addition, black mark is also set on the eaves for visual identification.

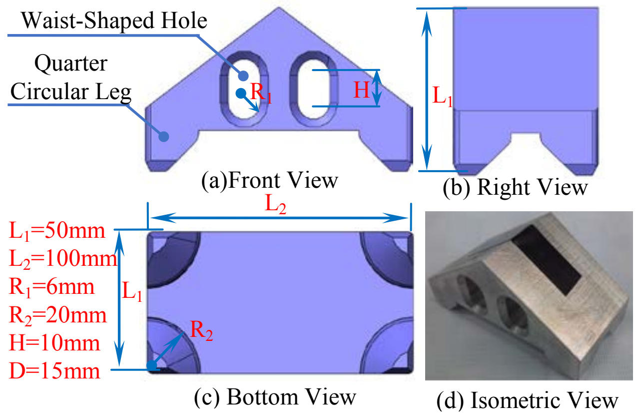


Fig.3 Structure of Rof-module

d) Warehouse

Warehouses are used to place modules, and are unified. The overall size is 279mm×103mm×153mm (length ×width × height), fixed in warehouse area A and B. Warehouse is able to accommodate 15 Squ-modules and 4 Rof-modules and shown in Fig.4.

(a) Front View

(b) BackView

Fig.4 Structure of warehouse

B. Building Task Descript

This platform mainly simulates human construction activities to reflect all planning and organizing methods of human activities. In initial state, all Socibots randomly distribute in active region, and all modules are placed in warehouse A. Then, human send task to Socibuilder system through HCI to confirm what to build. Next, the system will decompose and distribute the task step by step till the Socibots can execute. In the process of execution, a large number of temporal relations and dynamic planning and organization will be handled automatically. Finally, the system completes task within the specified time.

In order to complete the simulation successfully, two basic constraints are given as following:

a) All modules must be transported from warehouse area A to B before they are used in building. This constraint urges system to decompose the work using heterogeneous individuals and imitates transportation of materials from the distance to worksite.

b) Building task should meet executable logic to finish its given task.

C. Significance of Proposed Platform

SociBuilder system is established to implement a semi-physical research on the theories of swarm robotics, especially for complex logistics task. We could also conduct validation process of swarm theories as following: a) System architecture; b) Task decomposition and allocation; c) Self-organization method; d) Task automated planning; e) Multi-robot cooperation; f) Knowledge sharing and learning in swarm system.

In the perspective on functional level, this platform is able to execute the following task: a) Foraging task; b) Transporting task; c) Building task; d) Task of survey; e) Formation task; f) Collaboration; g) Self-reconfiguration.

III. System Architecture

SociBuilder system structure designed to simulate human thought and society includes three layers: Human-Computer Interaction Layer, Planning Layer and Execution Layer, as shown in Fig.5.

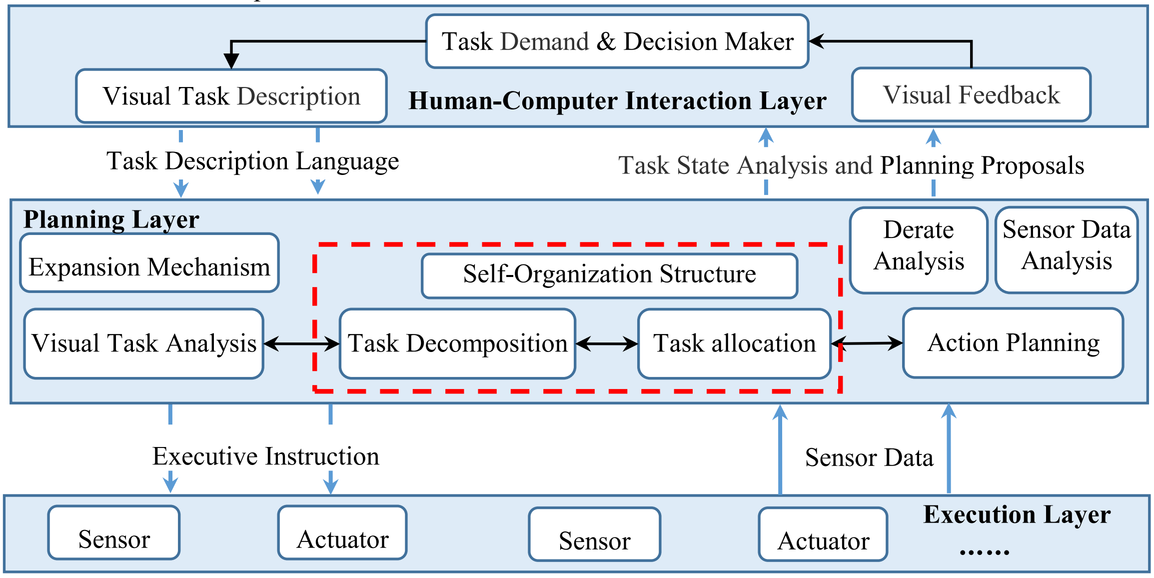


Fig.5 System structure of SociBuilder system

Human-Computer Interaction (HCI) layer: Robots should serve for human, but there are some very important issue between human and robots that the ways human declare task target and how robots inform task state with a simple human acceptable manner. In current layer, visual task description and visual feedback are included, human task requirement conducts as output to Planning Layer, and data of visual feedback set as input from Planning Layer.

Planning layer: This layer establishes a bridge between task and action [13] to deal with sequence of movements. It consists of eight parts:

a) Visual task analysis

All tasks could be considered as changes of states of objects with the time. This analysis is responsible for task interpretation from visual task to formal language that computer could understand. This interpretation needs to meet the constraints of real-world and task requirement. For example, we put a book on the desk, and then put a cup of coffee on the book, we could not put the coffee in the air and then put the book under the cup as like in virtual operation, and we also need to keep the cup horizontal to prevent coffee spill out in whole process. In this paper, we interpret building task just considering position constraint and physical laws not process constraint.

b) Task decomposition

Decomposition is an effective method to implement complex tasks，which could divide complex tasks into some simple sub-tasks [5,6,14] according to task process, task property and etc.

c) Task allocation

Agent technology is utilized in this system. We not only abstract Socibots as executive agents, also some agents are assumed for managing sub-agents. Every agent has the database about its states and capability. In this paper, we propose market method for task allocation[15].

d) Self-Organization Structure

Self-organization means no signal from external system to guide how to set relationship among individuals. We put forward a novel hierarchical organizational structure for swarm robotic society, which has the following characteristics: 1) agent has identification about level and the level changes with the agent capability; 2) agent could be created and disappeared in the level n-1; 3) Agents in the same level could allocate subagents of others; 4) Quantity of agents' level increases along with the growth of the system, but the first and the last level never change; 5) This structure makes system care for solution of task not the quantity of swarm robotics.

e) Action Planning

All tasks are able to be realized by a series of actions with sequential relation, but how to arrange when to do and what to do relates to this part [13]. We propose proposition/transition Petri networks to plan action, which is described in our another paper[16].

f) Expansion Mechanism

Additions and deletions of individuals are common phenomenon in swarm robotics, because of generation of new individuals and failure of older. This mechanism contributes to no change on system structure with variety of individual number. When one individual add to system, it will belong to one agent in the level n-1 in randomly method or others.

g) Sensor Data Analysis

Sensor data originates from sensors and reflects to state of system. This part picks up useful data and analyses to guide human behavior.

h) Derate Analysis

When system is not able to complete task perfectly, this function will provide suboptimal scheme; On the other hand, when the subtask cannot fully achieve the target, it will improve the index of other subtask or create a new subtask to ensure perform ability of task.

Execution layer: This layer contains all Socibots, regardless of whether it participates in task, which receives orders from Planning Layer as input and sensors date as output.

In addition, signal communication is an important issue for swarm robotic system, which is the basic of interaction and organization. We rule that agent just could communicate with subagent and up-agent and the number of subagents of one agent could not exceed 10 to prevent communication block.

IV. INDIVIDUAL DESIGN

A. Handbot

The Handbots are responsible for grabbing and building. It contains seven parts: support module, motion module, source module, control module, operation module, sensor module, and docking module, as shown in Fig.6.

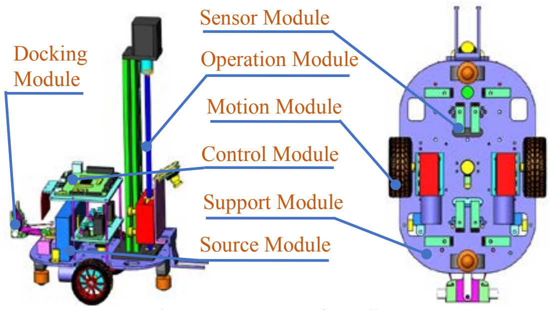


Fig.6 3D Prototype of Handbots

Support Module: Providing support for other modules with the size 180mm×230mm.

Motion Module: It is driven by two 12VDC motors and propped up by two universal wheels.

Source Module: The capacity of source is 9600mAh (12VDC), which has enough electricity for running about six hours and provide two type of interfaces: 5VDC and 12VDC.

Control Module: All input information needs to be handled by this module. It is able to communicate with host computer and control the motion of Socibots.

Operation Module: Two long fingers are designed on operation module and which has large motion rang in vertical direction from 10mm to 180mm.

Sensor Module: It is used to perceive environment and provides available information for system to make strategic.

Docking Module: It contains three parts: marking plate, passive interface and active interface. Marking plate provides relative information of position for docking. Passive interface presents W shape for easily docking and contains two freedoms: yam and pitch. They depend on elastic elements (elastic and leaf spring) to recover original shape, and guarantee flexible motion. Active interface is also called operation module.

As control system, the main board collects information from infrared sensors, cameras and 2.4G wireless, and then drives three motors. The whole control system is divided into seven parts: main board, LCD screen, stepper motor drive, cameras (2), NRF2.4G wireless, DC motor drives (2) and infra-red sensors (8), as shown in Fig.8.

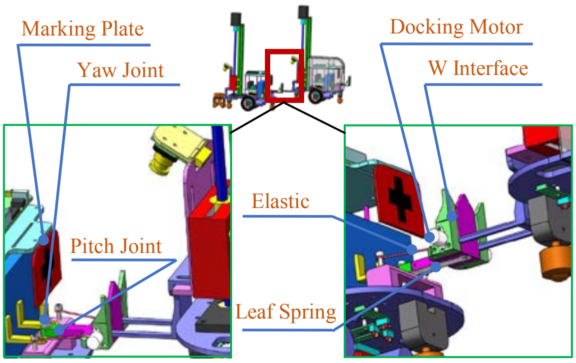


Fig.7 Docking structure

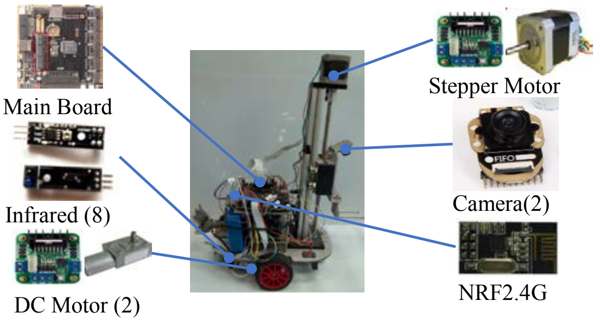


Fig.8 Control system of Handbots

B. Transbot

The Transbots are responsible for transporting modules, which contains six parts: support module, motion module, source module, control module, loading module, and sensor module, as shown in Fig.9.

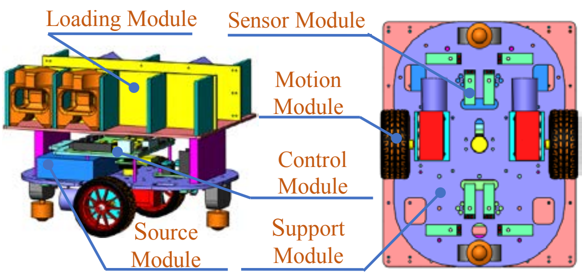


Fig. 9 Transbots structure

The function of support module, motion module, source module, control module and sensor module is same to Handbots. As loading module, it is set on the top of Transbos and able to accommodate 4 Squ-modules and 2 Rof-modules.

The whole control system is divided into five parts: main board, camera, NRF2.4G wireless, DC motor drivers and infrared sensors (8), as shown in Fig.10.

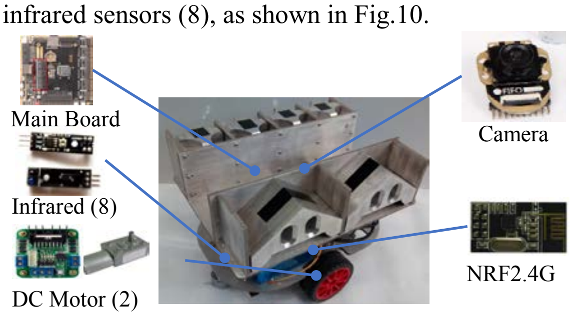


Fig.10 Control system of Transbots

V. Experiments

A. Self-assembly experiment

During the self-assembly experiment, various robots are reconfigured to adapt to environment, which makes the system apply to more situation. For example, if only one single Socibot attempt to pass through the extremely slope obstacle, it will fall down, as shown in Fig.11 (a) ~(c). In order to overcome this slope, a scheme that multi robots link together inline, as shown in Fig.11 (d)~(f). Besides, this experiment is able to verify the navigation function of visual and the docking function.

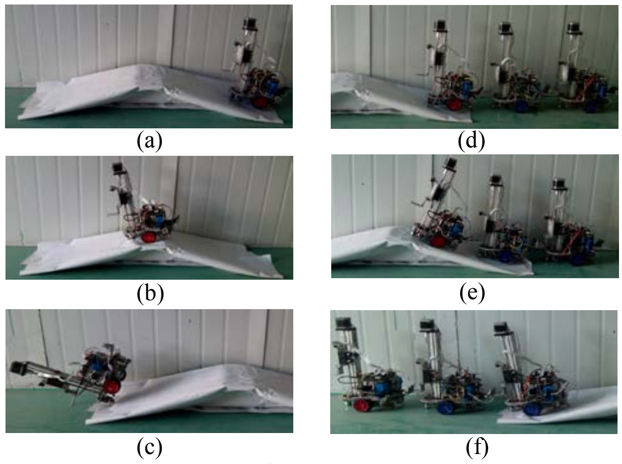
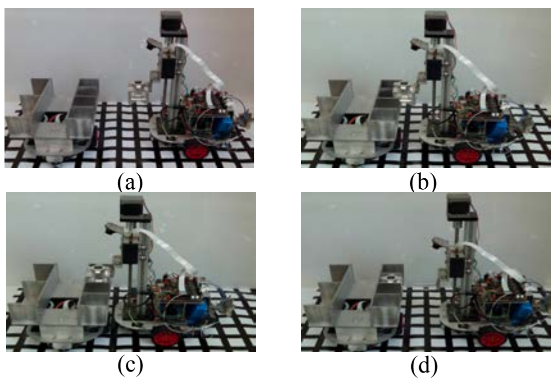
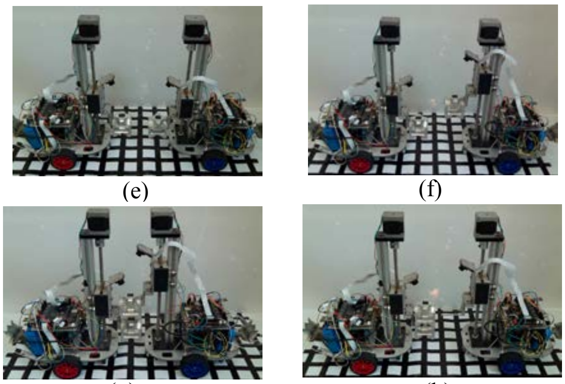


Fig.11 Self-assembly experiment

B. Multi-robotics Cooperation

Multi-robotics cooperation is an important issue in both multi-robotics and swarm robotics, which needs robots interactive information constantly and act coordinately. In this part, we display two experiments to validate the cooperative function among Socibots, as shown in Fig.12. The first one shows that Handbot and Transbot seek their relative position relying on coordination system using infrared and bottom camera. Then, Handbot puts Squ-module on Transbot depending on visual system. The whole process is shown in Fig.12 (a)~(d). Another experiment exhibits the scenario that Handbot piles Squ-module on another module which is handed in another Handbot, as shown in Fig.12 (e)~(h). This cooperation increases the ability of handing.





(e) (f)

(g) (h)

Fig.12 Cooperation experiments

C. Building task

The design idea has been introduced in section II. In this experiment all Socibots are able to do path planning, and they can avoid collision depending on coordinate system and visual system. When path confliction emerges, one Socibots will have priority randomly. Besides, the order of building house is calculated by system to ensure the task be completed without collision between Socibots and modules. Notably, different individuals have different roles and they could change dynamically during experiment. For example, one Handbot belong to transport subtask agnet at begin, but it could be fited to building subtask agent at last. In Fig.13, the whole system is shown, which is completing the building task.

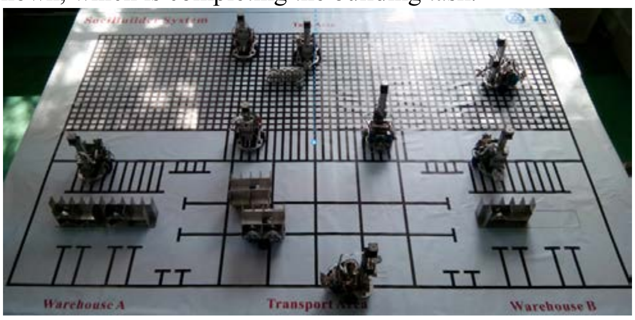


Fig.13 Building task experiment

VI. CONCLUSION AND FUTURE WORK

In this paper, a new concept of swarm robotics is proposed, in which the emphasis is mostly put on organization structure, rather than quantity.

Human building activity fully reflects human labor division and social organization structure, so we build SociBuilder system to imitate it. This system is consisted of four parts: active region, Socibots, warehouse and modules.

Autonomy of task-oriented and swarm robot system is the trend of robotics development in the following period. In this paper, SociBuilder system shows us a novel system structure, which is subdivided into three layers: human-computer interaction (HCI) layer, planning layer and execution layer. This structure makes the system flexibly, unpredictably and infinitely increases or decrease units and has task-oriented mechanism.

Finally, three types of experiments have been implemented to verify our theories and platform function. We hope to build a swarm robotics society, which can serve for human automatically and efficiently.

Future research will mainly cover the following aspects: Firstly, collaboration in unstructured environment would be investigated, which enhances application of system. The second is to put forward a novel method of HCI that when we assign task we only need to operate objects on monitor video. The third is to find out a method for function combination in Multi-robotics. Finally, robustness of organization should be studied to ensure the completion of tasks.

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