Method of Autonomous Approach, Docking and Detaching Between Cells for Dynamically Reconfigurable Robotic System CEBOT*

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The concept of the new dynamically reconfigurable robotic system (DRRS) are its realization as the cell-structured distributed robotic system CEBOT are discussed in this paper. CEBOT can reconfigure itself to optimal structure depending on purpose and environment. These robotic systems are very advantageous for space robotics, since the available resources are limited in space. This robotic system is possible owing to the use of separable self-controlled units called "cells"; thus the robotic system is called a cell-structured robot # (CEBOT). CEBOT has unique features such as a dynamically reconfigurable structure, on-line task adaptability, fault tolerance, etc. With simple elementary cells clustered into large structures or modules, complicated tasks can be executed (this concept is found in biological organisms). We propose this concept, control and sensor system structure, and automatic approach control. The efficiency of CEBOT is shown by the results of automatic approaching, connecting and separating experiments.

Key Words: Robotics, Automatic Control, Mechatronics, Self-Organized Robot, Rendezvous Docking

1. Introduction

The dynamically reconfigurable robotic system (DRRS) is a new kind of robotic system. It can reconfigure itself to optimal structure depending on purpose and environment. These robotic systems are very advantageous for space robotics, since the available resources are limited in space. This robotic system is possible owing to the use of separable self-controlled units called "cells"; thus the robotic system is called a cell-structured robot # (CEBOT). The fundamental concept of the new robotic system is shown in Fig. 1. To realize DRRS, we propose a cell structure, an approaching method, and an optimal structure-decision method⁽¹⁾⁽²⁾. The DRRS soft- and hardware system is a self-constructing cooperating system like it can be found in biological structures.

The cells are able to communicate, connect and separate automatically. If single cells are damaged, the DRRS is able to repair or replace them and therefore maintain system function. Existing robot systems cannot modify their own structure or software. Since DRRS is capable of adapting itself to changing environmental conditions, it is a very flexible system applicable in space, factories and also in unfavorable environments.

In this paper, the results of automatic approach-

Fig. 1 Example of DRRS working inside a tank

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ing, connecting and separating experiments are presented. All the experiments have been done with the series II robot, an advanced form of the series I robot with higher performance and reliability.

2. Form and Function of the Cells

A fundamental demand of cell construction is to enable easy connection and separation, and also to maintain a holding force for connection. The cells must be able to transmit information and electric energy through a connector. Cells of series I had to approach the target cell very exactly due to the cell geometry and the coupling mechanism (see Fig. 4 (a)). Series II, providing a new mechanism (hook type), shown in Fig. 2, improved the coupling characteristics. The cone-shaped front and back guide the cells during coupling (see Fig. 3 and Fig. 4). Both series have an area of positions from which coupling can be achieved. The ratio of this connectable area and the cell front area of series II (4%) is much larger than that of series I (0.3%, see Table 1). Figure 4 shows a comparison of series I and II and Table 1 some technical characteristics. If the center of the moving cell is in the connectable area (hatched area in Fig. 4), docking can be carried out closing the

Fig. 2 The coupling mechanism (hook type)

Fig. 3 Picture of coupled robot cells

hook. Docking procedures have been successfully executed on an even surface with one two-wheeled traveling cell and one target cell incapable of movement. The target cell has castor rolls on the bottom to reduce friction with the surface when connected.

3. The Sensor System and Approaching Method

Connection and separation between cells of the series II robot is carried out in five steps.

- Step 1: After the target cell is selected out of all the possible object cells, the traveling cell recognizes its position.
- Step 2: The traveling cell approaches the object cell approximately.
- Step 3: The orientation of the target cell is detected and the traveling cell moves to the back side of the target.
- Step 4: The traveling cell approaches further and enters the area where connection can be performed.
- Step 5: Connection by tightening of the coupling mechanism.

If obstacles appear during the approach, the traveling cell recognizes them and avoids collision by choosing another path. In section 4 of this paper, results of the experiments from step 1 to step 5 are shown.

The traveling cell of series II has three infrared photodiodes (PD1, PD2, PD3), and three ultrasonic

Table 1 Technical characteristics

	Series I	Series II
Frame Size [mm]	190×90×50	176×126×90
Weight [kg]	1.2 (Mobile Cell) 1.2 (Target Cell)	2.7 1.0
Shape of Connective Surface	Flat	Flat + Truncated Cone
Coupler Type	Small Hooks × 4	Large Hooks × 1
Coupler Actuator	S.M.A.	DC Motor
Wheel Actuator	DC Motor	Pulse Motor
Connectable Area Ratio [%]	0.3	4.0

Fig. 4 Connectable area

sensors (one transmitter, USS-T; two receivers, USS-Rr and USS-R1). The object cell has eight strong-focused photodiodes in eight different directions in 45° intervals (see Fig. 5). The traveling cell recognizes the position and orientation of the object cell by receiving light from the photodiodes of the object cell. Obstacles are recognized by the ultrasonic sensors. Experiments using the control system shown in Fig. 6 and the approach algorithm (steps 1 to 5) have been performed. The traveling cell rotates around its axis using the control algorithm shown in Fig. 7 and recognizes the position of the object cell according to the maximum output of the photodiode PD2. The cell proceeds forward as long as the output

Fig. 5 Arrangement of photosensors

Fig. 6 Control system structure

of the photodiode PD2 does not exceed a default set level. During step 2, the path direction is controlled by minimizing the difference of the photodiode outputs PD1 and PD3. When we light the photodiodes of the target cell one after another, the relative attitude can be detected (step 3, see Fig. 8) and the traveling cell moves along a corresponding default path. When it is behind the target cell, it approaches further, reaches the connectable area (step 4) and finally connects by closing the hook (step 5, Fig. 9).

Fig. 7 Control algorithm, steps 1 and 2

Fig. 8 Control algorithm, step 3

4. Experimental Results

Figure 11 shows the results of experiments done with the traveling cell in various positions on a 40-cm circumference with the object cell in the center (see Fig. 10). Figure 11 shows a relationship between θ and number of LED recognized as maximum data value. In step 3 (see Fig. 8), the moving cell knows the attitude of target cell owing to lighting LED turning round. Recognition of the cell attitude is done efficiently as shown in Fig. 11. Figure 13 shows output of PD(1, 2, 3), the potentiometer of coupling mechanism, rotation of right and left wheels when two cells are set initially as shown in Fig. 12. Means of number

Fig. 9 Control algorithm, steps 4 and 5

Fig. 10 Relative position of the cells during the orientation sensor experiment

shown in Fig. 11 are shown as follows :

- 1; Approach: As shown in Fig. 17, wheels are turned on difference between PD1 and PD3 (see in Fig. 5).
 - 1-2; Hook close: When output value of PD2 reaches the settled value, the moving cell docks with the object cell by closing the hook of coupling mechanism. The hook position is measured by a potentiometer and the output value is shown in Fig. 13.
 - 2-3; Connection: The hook and the wheels are fixed so output value of potentiometer and both wheels distances do not change.
 - 3-4; Hook open: Opening of the hook is shown as changing value of potentiometer voltage.
 - 4-; Detachment: PD1 value is decreasing because the moving cell moves away from the target cell.
- The PD values are not measured while two cells are connecting. All these experiments have been done without obstacles and the approach, connection and separation have been executed autonomously. The results show the effectiveness of the new cone shaped series II robot. The new robot works much better due to the new geometric form, its bigger connectable area ratio and the new sensor system. Obstacle detection by the ultrasonic sensor works very well for flat obstacles, inclination angles below 20 degrees and a distance of 0.05 m to 0.7 m (see Figs. 14, 15 and 16).

Fig. 11 Activity of the photodiodes dependent on the angle

Fig. 12 Setting position for the automatic approach experiment

Fig. 13 Experimental results

Fig. 14 Relative position between traveling cell and obstacle

(a) USS-R_r

(b) USS-R_l

Fig. 15 Output of the ultrasonic sensor dependent on obstacle distance

Fig. 16 Output of left and right ultrasonic receivers dependent on obstacle inclination angle

5. Conclusions

The results of experiments performed with the dynamically reconfigurable robotic system (DRRS) are as follows ;

- a) The new coupling mechanism allows uncertainty in the position of the target cell. The effectiveness could be proved with experiments.
- b) The realization of the DRRS system (CEBOT) enables autonomous approach, connection and separation, which have also been shown experimentally.

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