Seventh International Conference on Control, Automation,
Robotics And Vision (ICARCV'02), Dec 2002, Singapore

Development of Pneumatic Cellular Robots Forming a Mechanical Structure

N. Inou, H. Kobayashi and M. Koseki

Department of Mechanical and Control Engineering,
Graduate School of Science and Engineering,
Tokyo Institute of Technology, O-okayama, Meguro-ku, Tokyo, Japan
E-mail: inou@mech.titech.ac.jp,
hirokazu@stu.mech.titech.ac.jp,
koseki@mech.titech.ac.jp

Abstract

This study deals with group robots forming a mechanical structure. In this paper, we address the concrete motion mechanisms of the robots. Each robot has a cubic shape with pneumatic actuators. It rotates with a corner of the robot as an axis. To realize the movement, we propose two kinds of mechanical devices. One is a stabilization mechanism that the pneumatic actuator stably forms an arched shape. The other one is a rotary selective valve for minimizing pneumatic elements. This paper also reports a demonstration of the pneumatic robots in hardware.

Key words: Cellular Robots, Modular Group Robots, Pneumatic Actuator, Super Mechano-System

1 Introduction

The purpose of this study is to develop cellular group robots that adaptively form a mechanical structure under a mechanical condition. Each cellular robot has identical mechanical functions and information processing. Missions of the cellular robots are assumed to accomplish a task by their cooperative behavior.

Fig. 1 illustrates an example of the missions. A moving load lies at one side but cannot reach the opposite side. The mission of the cellular robots is to help the moving load pass over the gap by forming a bridge-like mechanical structure. After finishing the mission, they must return to their original place.

Our previous papers reported the information processing required of the cellular robots to execute the mission as in Fig. 1 and proposed algorithms based on local rules considering mechanical parameters [1,2]. However, mechanisms of the cellular robots to realize the structural formation were not yet examined. This paper describes the concrete mechanisms of the cellular robots.

With respect to research studies on reconfigurable group robots forming a structure in hardware, many kinds of joint mechanisms were proposed. Fukuda et al. reported on "CEBOT" that had a joint function with cone-shaped coupling mechanism[3]. Chirikjian developed metamorphic robots that had a function of self-reconfiguration[4]. The robots formed various structures with linkage units. Murata et al. reported on "fractum" that realized self-assembling. The joint mechanism was composed of magnet and electromagnet[5]. Their recent study successfully demonstrated three-dimensional structural formation[6]. Yim et al. studied "Polybot" which was a modular reconfigurable robot system. It formed a chain structure and realized a locomotion connecting with grooved pins to a mating connection plate[7].

It is a popular way to use electric motors for realizing motion mechanism of the robots in the above reports. Mechanical or magnetic elements are also useful for realizing connection function of the robots. Although these mechanisms have shown validation to embody the robots, there is still room to study and develop other mechanisms for application under various conditions.

Here, we pay attention to creatures called invertebrate animals which have soft bodies, for instance, earthworm, caterpillar, sea-anemone and so on. These animals have hydrostatic skeletons that can change shape or length of the body adjusting their inner pressure of water. They can also easily maintain a static structure. That is, the hydrostatic skeleton juggles the movement and the structural support with only hydraulic elements. Learned from the living system, we focus on pneumatic mechanism that realize motion and connection functions. These functions have the potential to construct a reconfigurable support structure in a specific environments such as in the space.

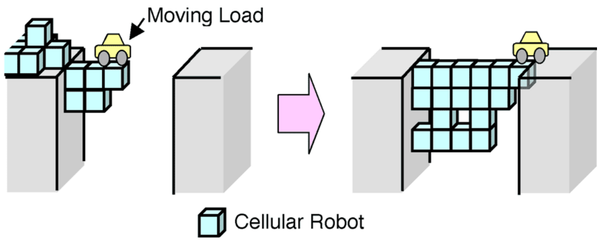


Fig. 1 Idea of cellular robots forming a bridge structure

2 Pneumatic Cellular Robots

Concept of pneumatic cellular robots is illustrated in Fig. 2. The robot is driven by compressed air. That is, pneumatic actuators with flexible bellows are used for movement of the robot. As compressed air elongates the pneumatic actuators, the robot rotates around a binding site of joint elements. Binding and releasing of the joint elements are also operated by compressed air. Arrangement of the robots is formed by sequential rotational movements. Three-dimensional structural formation is realized if all faces of the robot have pneumatic actuators. This study examines two-dimensional case for the first step.

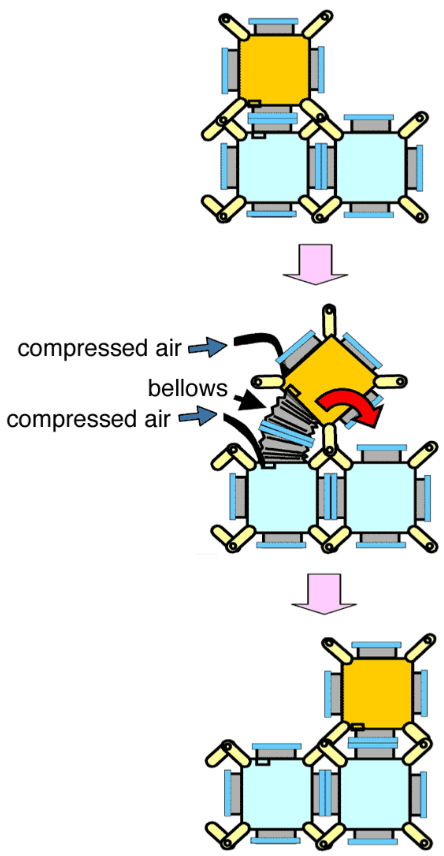


Fig. 2 Concept of pneumatic robots

Fig. 3 shows the developed pneumatic cellular robots. Each cellular robot is about 20cm by 20cm scale and its weight is about 4 kg. The pneumatic robot has a rotary valve that supplies a compressed flow to a selected port among multi-channel ports. The concrete mechanism of the rotary selective valve is described in the chapter 4.

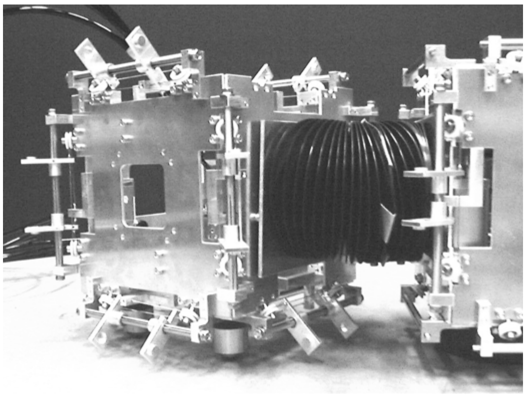


Fig. 3 Developed pneumatic cellular robots

3 Stabilization Mechanism

To realize structural formation with the proposed pneumatic robots, bellows must perform stable motions. They must be satisfied with the following two functions.

One is stable contraction. Although a bellows smoothly elongates the length, it does not have a function of contraction itself. When compressed air is not supplied, the bellows tends to be dragged as shown in Fig. 4.

The other one is stable elongation. As each cellular robot independently moves, bellows must be separated even in elongation. It is however difficult to form an arched shape with only bellows. Fig. 5 shows uncontrollable elongation. The cellular robot does not produce effective rotational force in this condition. It requires a support mechanism to produce stable formation in elongation.

To solve the above mentioned two problems, we propose a stabilization mechanism. Fig. 6 shows the mechanism. Constant force springs are mounted on the body of the robot. The constant force spring is made with a thin metallic plate, which is rolled up on a cylindrical body. The spring produces a constant force in any displacement of the spring. Owing to the spring property, the bellows contracts its length when the air pressure is out as shown in Fig. 7.

Moreover, arched formation of bellows is realized by control of the constant force springs. Fig. 8(a) shows that left side of the constant force spring is free in length and right side is fixed. This constrained condition transforms the bellows to the right way forming an arched shape. Motion of the bellows produces rotational force that effectively applies to the other robots as shown in Fig. 8(b). This stabilization mechanism realizes 180 degrees rotation of the cellular robot under the condition that each bellows is thoroughly separated.

Length of the constant force spring is controlled by two pins attached to a joint element as shown in Fig. 9 (a). Motion of the joint element is performed by an air-cylinder. When the joint element is closed by compressed air, the cylindrical body rolling up the constant force spring is automatically fixed with closing motion of the joint element as shown in Fig. 9 (b). Thus, the bellows is ready for arched formation with only closing the joint element used for a rotational axis.

As the present mechanism uses a strip-shaped constant spring, the motion is limited in the two-dimensional plane. It is however possible to develop three-dimensional motions if we use three-dimensional type of constant force springs.

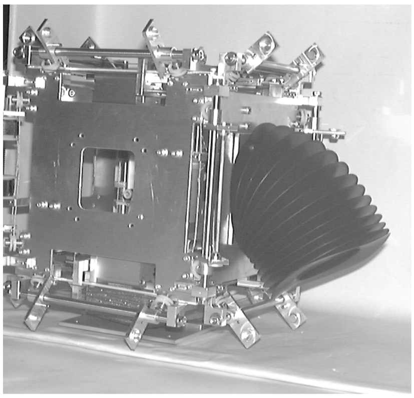


Fig. 4 Dragged problem of bellows

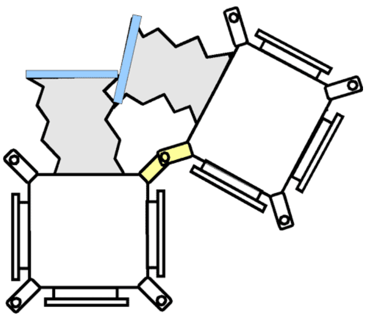


Fig. 5 Uncontrollable problem in elongation

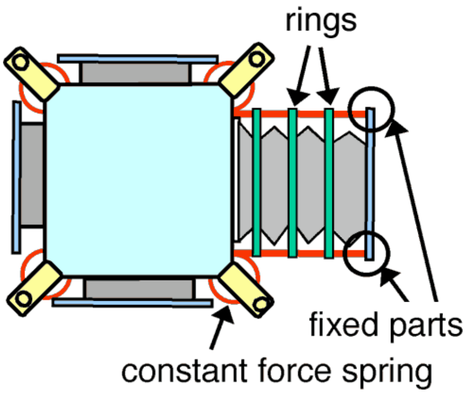


Fig. 6 Proposed stabilization mechanism

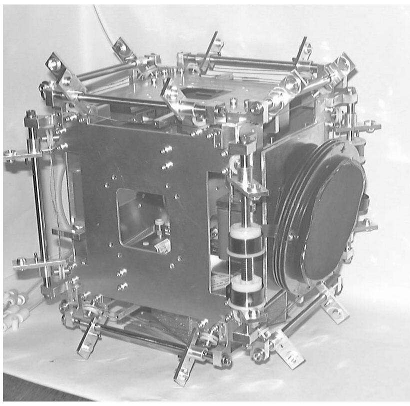


Fig. 7 Effect of constant force springs in contraction

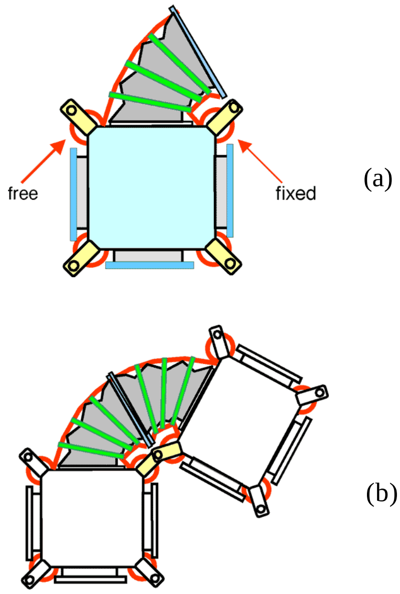
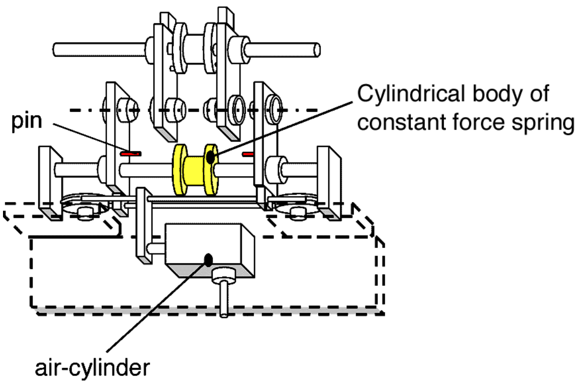
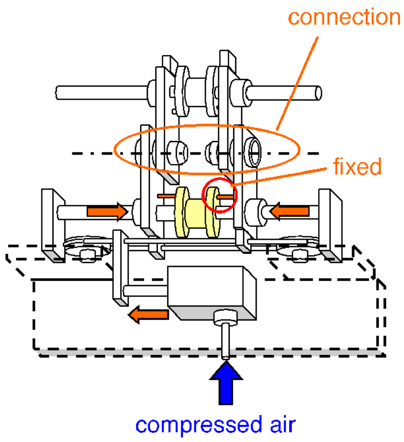


Fig. 8 Effect of stabilization mechanism in elongation
(a) arched formation of bellows,
(b) toward 180 degrees formation by two bellows



(a) released state of joint element



(b) closed state

Fig. 9 Mechanism controlling constant force spring

4 Rotary Selective Valve

Pneumatic actuator system needs many air tubes if conventional valves were used. Usually one air cylinder requires one set of air tube and air valve for supplying compressed air. In case of a three-dimensional robot system, one robot needs eighteen air tubular units because one cubic frame has six faces and twelve sides. It needs much space to store them in a robot. To solve the problem, we propose a mechanism to select a port among multi-channel ports.

The mechanism is shown in Fig. 10. It consists of a cylindrical rotor and a state that has multiple outlet ports. This study provides twelve outlet ports for two-dimensional rotational movement using two robots as described in the next chapter. Compressed air enters the input port through a magnetic valve. The channel port is selected by rotation of cylindrical rotor, which is controlled by a stepping motor. This mechanism selects only one flow port among twelve ports. The mechanism is simple and useful for reduction of number of air elements.

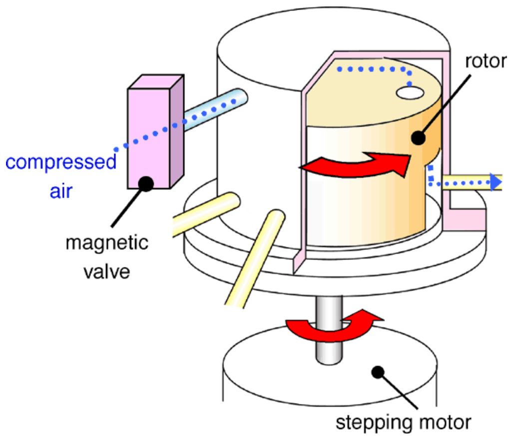


Fig. 10 Rotary selective valve

5 Performance Test

Validity of the above proposed mechanisms was examined by using two cellular robots. Compressed air was supplied by an air compressor. The air pressure was set about 0.35 MPa. The magnetic valves and the rotary selective valve of the robot were controlled by a personal computer using digital I/O boards. Demonstration was performed in a horizontal plane.

Fig. 11(a) shows the initial arrangement of the two robots. The right side robot was fixed on the flat floor in advance and the left one was a moving part in this case. Fig.11(b) shows the beginning of expansion of bellows. One side of joint mechanism was released and bellows was stably arched by supplied compressed air. The left side robot was rotating around an axis that was in common connection of the two robots.

Then the right side robot successfully performed 180 degrees rotation. After the rotation, the robot connected to the top surface of the fixed robot as shown in Fig. 11(c). After the connection, two elongated bellows were contracting as the air pressure was out as in Fig.11(d). Fig.11(e) shows the finishing state of 180 degrees rotation.

Fig. 11(f) shows a further rotational motion by expanding bellows. Fig. 11(g) shows that the rotational robot connected to the right side surface of the fixed robot. Fig. 11(h) is the final arrangement of the robots after 180+180 degrees rotations.

6 Discussion

The developed pneumatic actuator easily moves with low air pressure because contraction of bellows is performed by constant springs. It needs only pressure of about 2 KPa to expand the actuator. Moreover, required pressure decreases with scale up. Joint element also does not need large torque because only passive rotation. Air cylinders for the joint function however need more than 0.17 MPa. The required pressure of the present mechanical model is constrained by the air cylinders. The settled 0.35 MPa in this experiment takes a stability margin for the air cylinders.

The present air supply method needs one external air tube for each cellular robot. It may occur a problem in motion when many cellular robots form a structure. To solve the problem, we have a plan to develop air supply method as shown in Fig. 12. That is, air supply is performed through each cellular robot. When a cellular root is jointed with other robots, air paths in the robot are opened to neighbor ones. Air outlets of unjointed sides of robots are normally closed. This method minimizes the number of air tubes.

The present model also needs external electric lines. It is possible to eliminate them if we install electric power supply and controllers for pneumatic actuators in each cellular robot.

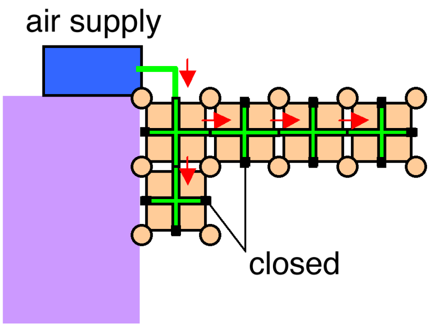


Fig. 12 Future air supply method

7 Conclusions

The proposed stabilization mechanism of bellows generated stable rotating propulsion. As the result, 180 +180 degrees rotations of a cellular robot was realized.

A rotary selective valve mechanism to reduce number of mechanical elements was devised. The performance was verified by mechanical experiments.

The proposed pneumatic mechanism is suitable for scale up because it does not gain the weight compared with other actuators. With scale up of the robot, adequate space is possible produced in the interior parts of the robot. For this reason, a mechanical structure formed by the pneumatic group robots will be available to supply habitation area in the space.

Acknowledgement: This study was supported by a Japanese Grant-in-Aid for COE Research Project supported by the Ministry of Education, Culture, Sports, Science and Technology, "Super Mechano-Systems"(No. 09CE2004). Concept of the pneumatic robots was suggested by Professor S. Hirose who was the leader of the COE Research Project. We greatly thank him for giving the chance of doing this research.

References

[1] N.Inou, S.Fukushima, N.Shimotai, S.Ujihashi: Study of Group Robots Adaptively Forming a Mechanical Structure (Effect of Mechanical Properties of Cellular Robots on Structure Formation), JSME International Journal, Series C, Vol. 43, No.1, 2000, pp.127-133

[2] N.Inou, N.Shimotai, H.Ogawa and S.Ujihashi: Study of Group Robots Adaptively Forming a Mechanical Structure (Information Processing Functions of the Cellular Robot Required for Transporting a Load to an Opposite Side) JSME International Journal, Series C, Vol. 43, No.1, 2000, pp.134-140

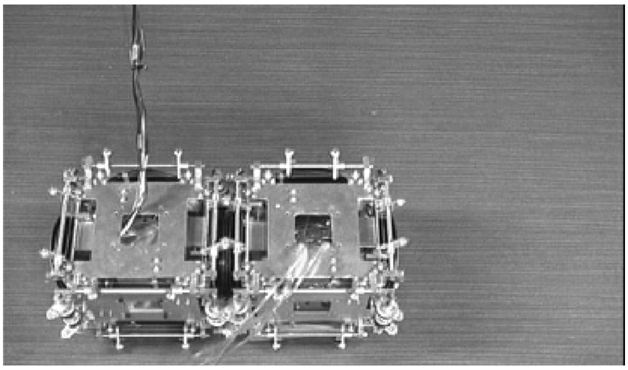
[3] T.Fukuda, S.Nagasawa, Y.Kawauchi and M.Buss: Structure Decision Method for Self Organizing Robots Based on Cell Structures-CEBOT, Proceedings of the 1989 IEEE International Conference on Robotics and Automation,1989, pp.698-700

[4] G.Chirikjian and A.Pamecha: Bounds for Self-Reconfiguration of Metamorphic Robots, Proceedings of the 1996 IEEE International Conference on Robotics and Automation, 1996, pp.1452-1457

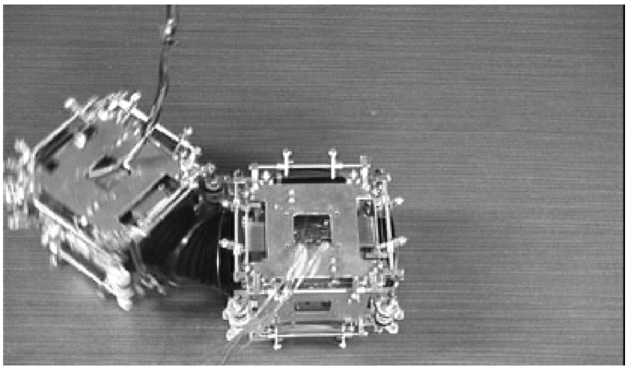
[5] S.Murata, H.Kurokawa and S.Kokaji: Self-Assembling Machine, Proceedings of the 1994 IEEE International Conference on Robotics and Automation,1994, pp.441-448

[6] A.Kamimura, S.Murata, E.Yoshida, H.Kurokawa, K.Tomita and S.Kokaji: Self-Reconfigurable Modular Robot (Experiments on Reconfiguration and Locomotion), Proceedings of 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2001), 2001, pp.606-612

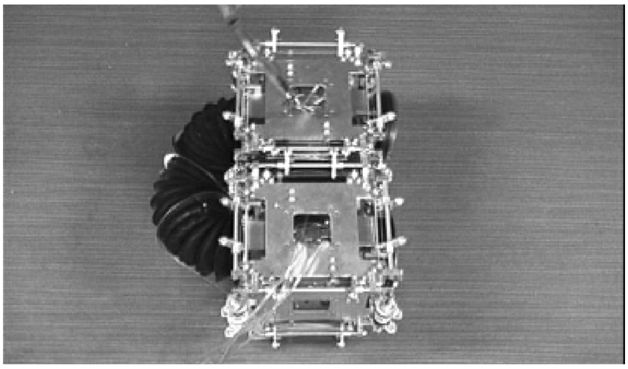
[7] M.Yim,D.Duff, K.Roufas and L.Kissner: Plybot: demonstrations of modular reconfigurable robot, Video Proceedings of the IEEE International Conference on Robotics and Automation, 2000



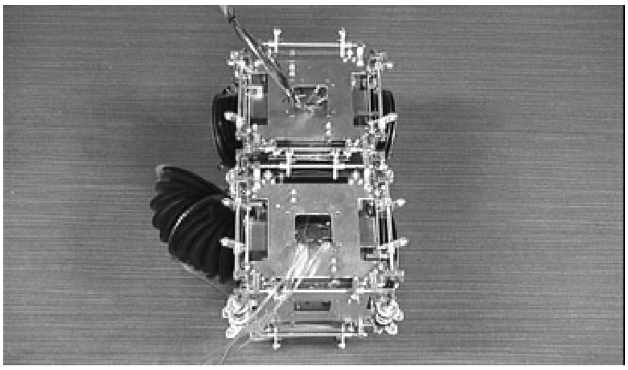
(a) Initial arrangement of cellular robots



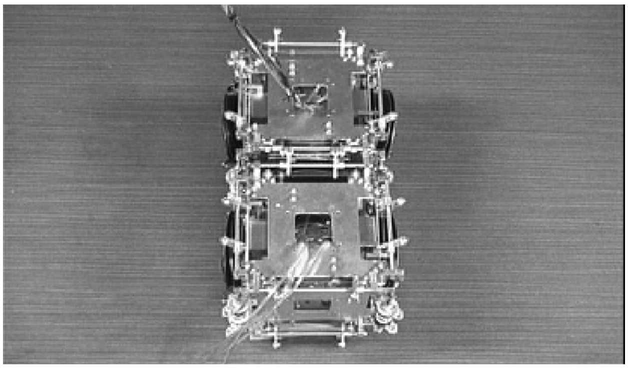
(b) Rotative moving by expansion of bellows



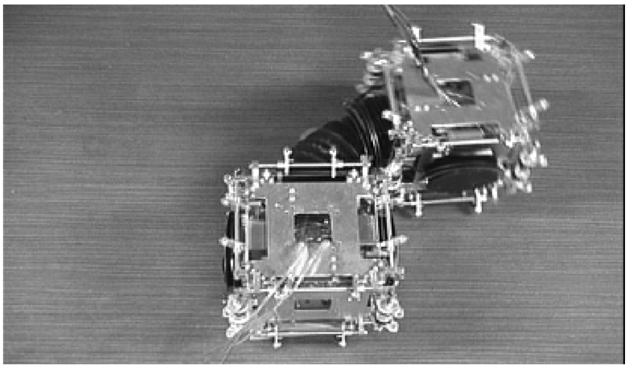
(c) Connecting to the top surface of the fixed robot



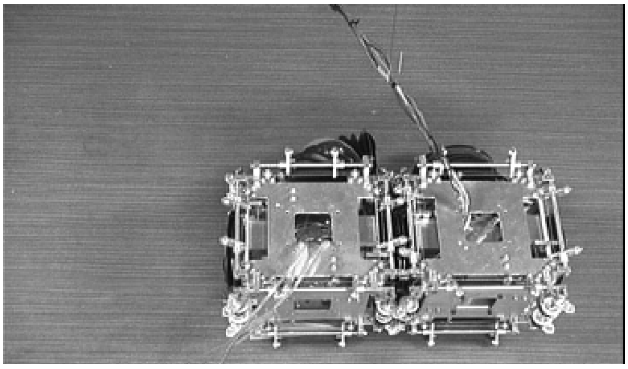
(d) Shrinking bellows after connection



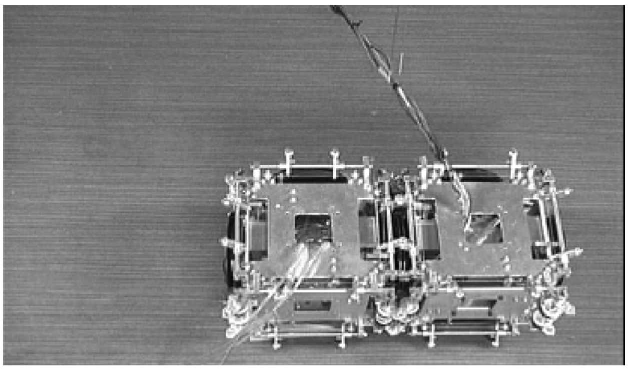
(e) Finishing 180 degree rotative motion



(f) Further rotative moving



(g) Connecting to the right side surface



(h) Final arrangement of robots after rotative motions

Fig. 11 Consecutive rotative motions of the pneumatic robots.