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Development of an Autonomous Flexible Robot that Uses No Explicit Sensors or Controllers

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Abstract: Recently, various robots that have many degrees of freedom have been developed and applications for practical use like a rescue operation, domestic robot, and so on, have attracted much attention. However, it is difficult to control the robot autonomously in the real environment, because, in order to control the many degrees of freedom, we have to observe many states, calculate huge amount of information, and operate many actuators. In this paper, we consider a flexible robot that perceives inclination of a slope and goes up the slope without sensors or controllers. To demonstrate the effectiveness of the proposed framework, we have developed a prototype robot and conducted experiments. As a result, the robot has perceived inclination and has been able to go up a gentle slope autonomously. We can conclude that by designing the body for utilizing the properties of the environment, we can realize autonomous robot that has no explicit sensors or controllers.

Keywords: Flexible robot, Column robot, Autonomous robot, Properties of the real world,

I. INTRODUCTION

Recently, various robots that have many degrees of freedom have been developed and applications for practical use like a rescue operation, domestic robot, and so on, have attracted much attention[1]-[5]. However, it is difficult to control the robot autonomously in real environment, because, in order to control the many degrees of freedom, we have to observe many states, calculate huge amount of information, and operate many actuators in real-time.

On the other hand, insects and lower animals can behave autonomously in spite of the fact that their brains are very small and calculation abilities are restricted [6]. The reason why they can behave adaptively have not been clarified completely, but, it is consider that their bodies play important roles and reduce load of the brain [7].

In our conventional works [1]-[3], we have considered reinforcement learning for a real snake-like robot, and to reduce the size of the state action space, we focused on mechanical design of the robot and showed that time for learning can be extremely reduced and acquired policy can obtain generality by just utilizing the properties of the body without adding any modification to the algorithm of Q-learning. But these works, a computer is employed as a controller.

In this paper, we consider an autonomously flexible robot that perceives inclination of a slope and goes up the slope without sensors or controllers as the simplest example. To control the robot, we employ physical and chemical properties of the real world. We employ sodium hydrogen carbonate and citric acid. They are in the tanks of the robot and by mixing them with water, carbon dioxide is generated. The pressure of the carbon dioxide moves water, and the center of gravity of the robot moves. Thus, the robot moves with rotating. Inclination of the slope is perceived by the water without sensors, and many degrees of the robot are controlled by the physical dynamics. So, the robot can move autonomously without sensors or controllers.

To demonstrate the effectiveness of the proposed framework, we have developed a prototype robot and conducts experiments.

Ⅱ. PROBLEM OF CONVENTIONAL FRAMEWORK

In this paper, we consider that the problem of conventional framework is to assume the computer the brain. In general, animals have a brain, and it is considered that the brain is the origin of intelligence, and we tend to consider that the computer works as the brain, and the computer is indispensable for realizing intelligent behaviors. So, conventional robots have many sensors, and actuators, and a computer. The computer is used for processing information from the sensors to generate control signal of the actuators.

However, it is difficult to control robots with many degrees of freedom autonomously in real environment by conventional frameworks. Because, in order to control the many degrees of freedom, we have to observe many states, calculate huge amount of information, and operate many actuators in real-time.

In this section, to explain problems of the conventional framework, we divide them into three problems written below.

P1 PROBLEM OF MEASUREMENT

The number of sensors that robot can be installed has limitation. And in addition, there are same physical parameters that can not be measured. So, it is impossible to acquire all of necessary information of the real environment.

P2 PROBLEM OF MODELING

There are some physical parameters that we can not identify in advance, because the environment is unknown. Thus, we can not construct a model for the controller.

P3 PROBLEM OF REAL-TIME PROCESSING

As the complexity of environment increases, it is difficult to process all the necessary information in real-time, because the computational costs increase exponentially.

From the problem P1 to P3, it is difficult to apply conventional framework of control theory to autonomous robots that operate in the real environment.

On the other hand, insects and lower animals can behave autonomously in spite of the fact that their brains are very small and calculation abilities are restricted. Especially, adaptability of the animals is respectable. They can behave adequately at various situations, in spite of the fact that the situations are always different and the same situations never occur again. The mechanism how to realize the adaptability has not been clarified completely, but it is considered that their bodies play important roles and reduce load of the brains. For instance, by designing the mechanism and the parameters of the body adequately, the body can adapt itself to the environment without sensors or controllers. The adaptive behavior is realized by interaction with environment. So, states of the environment affect the body directly, and movement of the body is determined by dynamics of the environment. Thus, sensors and controllers are not required.

Ⅲ. PROPOSED FRAMEWORK

In this paper, we consider an autonomous flexible robot that uses no sensors or controllers as the simplest example. Fig.1 shows the proposed mechanism. In Fig. 1 (i), to explain clearly, only hoses between Ta and Tb are illustrated, and illustrations of the other hoses are omitted. Fig. 1 (ii) is the extended figure of Ta and Tb in Fig. 1 (ii). The shape of the robot is a column and the robot moves by rotating. To control the robot, we employ physical and chemical properties of the environment. The robot consists of flexible sheets, and has six tanks that contain water, and has twelve valves.

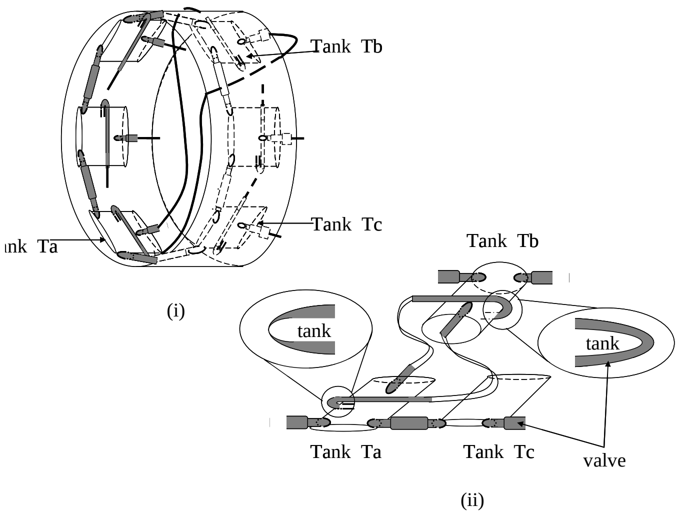
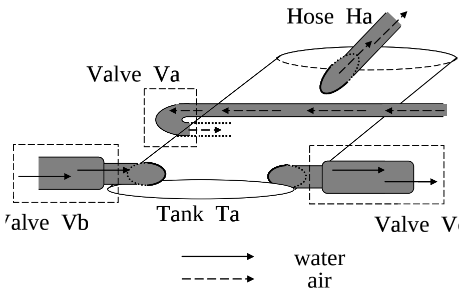


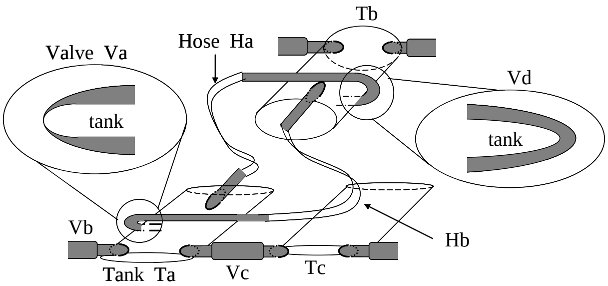
Fig. 1 Proposed mechanism

The tanks are made from flexible material. Fig. 2 (i) shows a tank. Each tank has three valves. Fig. 2 (ii) shows connection between tanks and valves. Va is the valve for deflating carbon dioxide of Tb, and Vd is the valve for deflating carbon dioxide of Ta. Ha and Hb are the hoses which connect Ta with Tb. Va and Vd are installed to a head of Ha and Hb. Vb and Vc are the valves for controlling water in the tanks.

As a beginning, we explain the valve which controls the pressure of the tanks. Opening and shutting of Va and Vd are switched passively with changing the shape of the body as shown in Fig. 2 (ii). In that case Ta is contracting and Tb is expanding. Fig. 2 (ii) shows Va is shut and V(d) is open. Therefore the pressure of Tb remains and the pressure of Ta deflates. By the chemical reaction, when Ta is expand, Va is open, and pressure of Tb is deflated.



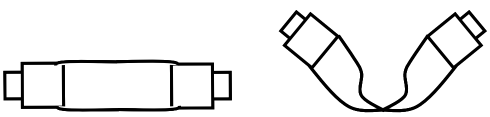
(i)



(ii)

Fig. 2 Mechanism of tank

Next, we explain the valve that controls water in the tanks. Fig. 3(i) shows the valve that is open and Fig. 3(ii) shows the valve that is shut. These valves are controlled by changing of the body as shown in Fig. 4. As the shape of the body is decided autonomously with changing the pressure of carbon dioxide and weight of itself, the valves which are integrated with the body are controlled autonomously too.



(i) (ii)

Fig. 3 Water valve

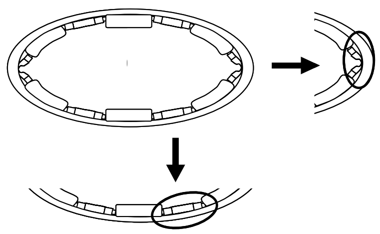


Fig. 4 Mechanism of valve

When the robot is put at slope, the water in the tank moves the lowest tank. The water is mixed to the sodium hydrogen carbonate and citric acid. Then, carbon dioxide is generated. By the pressure of the carbon dioxide, the water is pushed and moves to the next tank through the open valve. Fig. 5 shows a method of transference. Opening and shutting of the valve are switched with changing the shape of the body as shown in Fig. 4. The lower side of the body is twisted by the gravity, and the valve of the lower side is shut. So, water goes up as shown in Fig. 5. By the movement of the water, the center of gravity of the robot moves. Thus, the robot goes up the slope with rotating. When the robot rotated half around, the valve of lowest tank is opened and carbon dioxide of the highest tank is released. By repeating these cycles, robot can move. In the proposed mechanism, slope is perceived as the position of the water and the shape of the body, and control of the valves is realized with changing the shape of the body. Thus, no sensors and controllers are required.

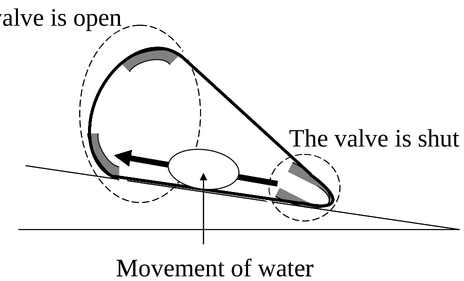


Fig.5 Method of transference

IV. EXPERIMENT

We have conducted experiment in order to confirm the behavior of the proposed robot.

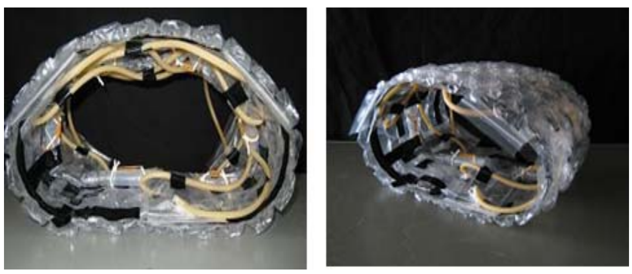


Fig. 6 Flexible robot

Fig. 7 shows experiment result. The robot perceives inclination of the slope and goes up the slope autonomously. The maximum angle of the slope the robot can go up was 4deg. We can confirm that the proposed robot perceived inclination of the slope and goes up the slope autonomously without sensors or controllers. So, by employing the properties of the real world, we can realize the autonomous robot that has no use sensors, and controllers.

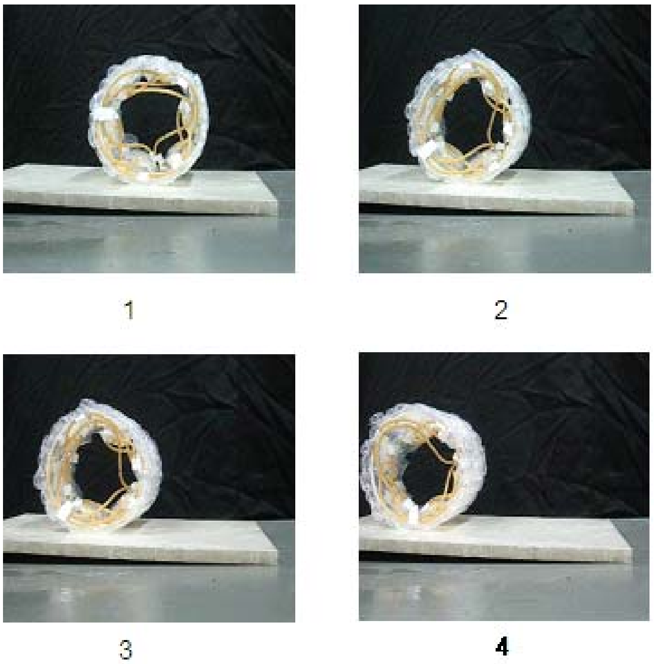


Fig. 8 Experiment result of 2deg

V. DISCUSSION.

First, we consider the method of perceiving inclination of a slope. The result clearly shows that the water can perceive inclination of the slope by the position of itself, and the robot can decide direction of movement autonomously.

Second, we consider rotating motion of the robots. In this paper, we used the valves which control the movement of water and the pressure of carbon dioxide. These valves behave adequately and autonomously by the mechanisms of the body and properties of the real world. So, we can regard every part of the robot as the processors. In the other words, we can consider that the real world is the information processing system. In the information processing system, as the necessary information is contained in itself, sensors are not required. And in addition, realizing of motion and processing of information are unified, so all information is processed in real-time. Thus, we can realize autonomous robot without sensors and controllers.

Ⅵ. CONCLUSION

In this paper, we have considered a flexible robot that perceives inclination of a slope and goes up the slope without sensors and controllers. We have developed a prototype and conducted experiments. As results, effective behaviors of the proposed framework have been demonstrated.

We can conclude that our proposed framework is effective for solving the problem of measurement, modeling, and real-time processing.

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