INTRODUCTION
We have many small diameter pipes that are cooling pipes for atomic power stations, boiler pipes, and gas or water pipe lines. They must be periodically inspected in order to protect the accident previously. Diameters and T-junctions of these pipes are different at the place where pipes change from the main to the branch. The inspection microrobot for these pipes must move different diameter and T-junction.

The in-pipe microrobot driven by wheels is very difficult to cross the step [1]. We have used cone-shape friction rings for the driving legs of the in-pipe microrobot. However, the microrobot driven by friction rings is also difficult to move in the pipe where diameter changes more than 3 mm [2].

Now, we propose a mobile microrobot that can surely move in T-junctions and a pipe whose diameter changes. The microrobot is constructed by the six rubber bellows as pneumatic actuator, six electromagnetic valves and six air feeding tubes. Outer diameter and natural length of the bellows are 16 mm and 108 mm, respectively. The bellows composes three somites by being arranged in two rows and three columns. The somite can make the arc like the bimetal by giving different pressure to each bellows. The arc somite can hold the pipe. The movement of the microrobot with three somites is imitating as for the accordion movement that is the movement of the snake operation.

The fabricated mobile microrobot was confirmed to move in different diameter pipes and T-junction whose diameters are between 44 mm and 90 mm. Its speed was 25 mm/s.

STRUCTURE OF IN-PIPE MOBILE ROBOT
A structure of the fabricated robot is shown in Fig. 1 and photograph shown in Fig. 2.

The robot is constructed by the five rubber bellows as pneumatic actuator, five electromagnetic valves and five air feeding tubes. Outer diameter and natural length of the robot is 33 mm and 304 mm, respectively. The bellows composes three somite by being arranged in two rows and three columns. Outer diameter and natural length of the bellows are 16 mm and 108 mm, respectively. The somite is defined forward of the robot as first somite, second somite and third somite. Each somite can make the arc like the bimetal by giving different pressure to each bellows. The first somite and third somite are mechanisms that hold the pipe and the second somite is mechanisms that obtain displacement.

An experimental apparatus for measuring the characteristics of the robot is shown in Fig. 3. A
computer controls six electromagnetic valves through a valve controller. Three air feeding tubes are connected from the electromagnetic valves to each bellows of the robot. An air compressor is connected to the entrance ports of the electromagnetic valves and feeds pneumatic pressure to stretch the bellows. A vacuum pump is connected to the exit ports of the electromagnetic valves and feeds vacuum pressure to shrink the bellows.

MOVEMENT OF SNAKE IN A PIPE
We observed snake's accordion movement in pipe. Fig. 4 shows the brief movement of an snake. When the snake moves a vertical pipe,

(1) The snake bends the body like the accordion and holds the pipe by the whole body.
(2) The snake stretches oneself to the moving direction. At this time, snake's lower part of the body continues the holding of the pipe.
(3) The snake bends the upper part of the body and holds the pipe.
(4) The snake extends the lower part of the body, and releases the holding of the pipe.
(5) The snake hauled in the lower part of the body. Afterwards, the snake bends the lower part of the body and holds the pipe.

Thus, the snake can move in the vertical pipe.

MOVING PRINCIPLE OF THE ROBOT
The moving principle of the robot shown in Fig. 5. The moving principle of the robot referred to the accordion movement of the snake.

As for step 0, negative pressure is given to all bellows.
Step 1: The third somite is bent and it holds of pipe.
Step 2: Positive pressure is given to the first and second somite and somite are stretched.
Step 3: The first somite is bent and it holds of pipe.

Step 4: Negative pressure is given to the third somite and the holding of the pipe is released.
Step 5: Negative pressure is given to the second somite. The latter half of the robot advances in this step.
Step 6: The third somite is bent and it holds of pipe.

The robot can move by repeating these steps.
MOVING EXPERIMENT

Moving speed of the robot
The moving speed of the robot is measured. Fig. 6 shows the experiment result. The using pipes to experiment are 44 mm, 60 mm, 70mm, 79 and 90 mm in the inner diameter. The air pressures used to experiment are 50 kPa and -80 kPa.

The robot is able to move in these pipes and a combined pipe of a different diameter. The moving speed confirmed no relation to inner diameter of pipe and average moving speed was 25 mm/s.

Moving test in a T-junction
We fabricated a T-junction of pipe line for moving test shown in Fig. 7. The pipe has 79 mm inner diameter. The front brake mechanism of the robot can be decided the direction of the bending by controlling the supplied pressure. The fabricated mobile robot is confirmed to move in T-junction and was able to move in the desired direction.

Brake mechanism characteristics
We measured the friction force that became brake force of a in-pipe mobile robot. Five kinds of acrylic pipes of the inside diameter 44 mm, 60 mm, 70 mm, 79 mm, and 90 mm were used in the experiment. Internal pressure of two bellows that compose the brake mechanism was changes in the experiment. Internal pressure of an inside bellows was controlled to be constant -80 kPa and the pressure supplied to an outside bellows was changed with -50 kPa, -25 kPa, 0 kPa, +25 kPa and +50kPa. The frictional force that occurs for the inside diameter of the pipe in shown in Fig. 8.

The measured friction force was 6.8 N in the pipe of 44 mm in the inner diameter when pressure in an outside bellows was +50 kPa,
and 2.5 N in the tube of 90 mm in the inner diameter. Therefore, the friction force was confirmed to depend on the inner diameter of the pipe. When pressure in an outside bellows was -50 kPa, the measured friction force was 2.6 N in the pipe of 44 mm in the inner diameter. Therefore, it has been understood that the friction force depends also on the pressure in an outside bellows of brake mechanism.

The pressure supplied to an outside bellows was controlled and the normal force which was generated at the braking mechanism was measured. The normal force that occurs for the inside diameter of the pipe is shown in Fig. 9. When pressure in an outside bellows was +50 kPa, normal force was 1.9 N in inner diameter 90 mm. Moreover, it was 2.3 N in the pipe of 44 mm in the inner diameter. The normal force is larger in case of the pressure of +50 kPa than the case of the pressure of -50 kPa. Therefore, it has been understood that the generated normal force depends also on an internal differential pressure of two bellows of the brake mechanism.

CONCLUSIONS

We propose the robot which is imitate the snake of accordion movement. The fabricated mobile robot is confirmed to move in different diameter pipes and T-junction whose diameters are between 44 mm and 90 mm. Its speed was 25 mm/s.

REFERENCES
