

A MICROROBOT MOVABLE IN FLEXIBLE PIPES LIKE THE LARGE INTESTINE

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1. Introduction

An inspection of the large intestine is very effective in order to prevent the large intestine cancer. A fiberscope is excellent for the inspection of the large intestine. However, the inspection by the fiberscope often attends many pains and injuring of the intestine. We are hoping the inspecting method for the intestine with no pain and no injuring of the intestine before the operation by the fiberscope. Many microrobots which can move in the large intestine have been proposed by several research groups [1], [2]. However, the sure moving in the large intestine has not been confirmed, because the actual large intestine in our human body is especially very flexible to the radius direction and the mobile moving in the flexible pipes is very difficult.

Now, we propose the new microrobot movable in a flexible pipe like the large intestine. We need the mechanism for moving in a flexible pipe surely. This mechanism is using friction force. The microrobot is able to hold a flexible pipe in the radius direction, and moves in the length direction. We use three rubber bellows in series. Six bulging rubber sheets are provided to the rubber bellows of two outsides. They are called friction braking mechanism. The friction braking mechanism works as a brake of the microrobot. The center rubber bellows is called as a moving element, because the microrobot is moved by stretching and shrinking of a rubber bellows.

When the rubber bellows of the friction braking mechanism is shrinking, six bulging rubber sheets spread in the radius direction and touch the flexible pipe. Then the spread bulging rubber sheets surely hold the flexible pipe. When the rubber bellows of the friction braking mechanism is stretching, spreading to the radius direction of the six bulging rubber sheets and touching to the large intestine are canceled. The rubber bellows are stretched by pneumatic pressure and shrunk by vacuum pressure. The stretching and shrinking of the rubber bellows are controlled by a computer and electromagnetic valves.

The new microrobot was confirmed to move at the speed of 12 mm/s in the pig's raw small intestine. We confirmed moving speed of 20.8 mm/s in the curving pipe. In this experiment, it was also confirmed that the microrobot is able to generate the traction force of 0.3 N.

2. Structure of the fabricated microrobot

Structure of the fabricated microrobot is shown in Fig. 1. The microrobot consists of two friction braking mechanisms and a moving element. These elements are driven by three bellows which are 16 mm in outer diameter, 11 mm in inner diameter, 27 mm, 31 mm long

and made of nitrile butyl rubber (NBR). Each bellows is an independent vessel. Three air feeding tubes, which are 2.0 mm in outer diameter, 1.2 mm in inner diameter, 2.0 m long, and 4.0 mm in outer diameter, 2.5 mm in inner diameter, 1.0 m long, are connected to three bellows of the friction braking mechanisms and the moving element. The rubber bellows are stretched by the supply of the pneumatic pressure and are shrunk by the supply of the vacuum pressure. The stretching and shrinking of the bellows are controlled by three electromagnetic valves and a computer.

Structure of a bulging friction sheet is shown in Fig. 2. The bulging friction sheet consists of six bulging rubber sheets which are 5 mm wide, 0.5 mm thick, 23 mm long and made of NBR. The length of the bulging friction sheet is 17 mm in the free condition and 14 mm when the pressure in the bellows is vacuum. The diameter of the bulging friction sheet becomes to about 32 mm. Then the bulging rubber sheets are strongly pressed to the flexible pipe like the large intestine. The friction force in the flexible pipe are made by the radial force of the bulging rubber sheets.

3. Experimental apparatus

An experimental apparatus for measuring the characteristics of the microrobot is shown in Fig. 3. A computer controls three electromagnetic valves through a valve controller. Three air feeding tubes are connected from the electromagnetic valves to two friction braking mechanisms and the moving element of the microrobot. 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.

4. Moving principle of the microrobot

The pneumatic and vacuum pressure are fed like as a time chart shown in Fig. 4. The mass flow rate through the electromagnetic valve is proportional to the absolute pressure of the upstream flow, because the electromagnetic valve is a kind of an orifice. The absolute pneumatic pressure at the time of stretching motion is more than two times of the pressure in the bellows in the time of shrinking motion. Then the supplying time of the vacuum pressure in the shrinking motion ($=t_s$) must be more than two times of the supplying time of the

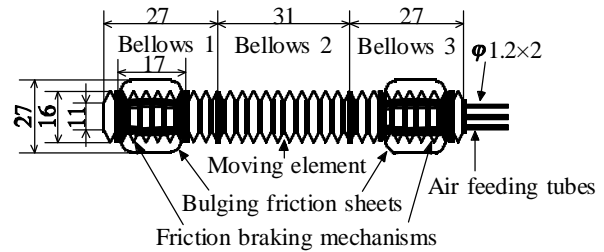


Fig. 1 Structure of the fabricated microrobot

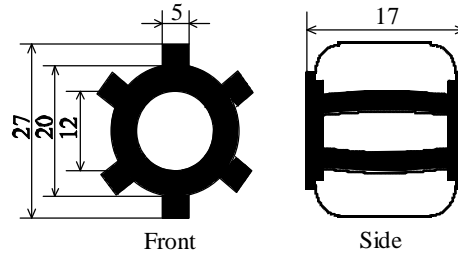


Fig. 2 Structure of a bulging friction sheet

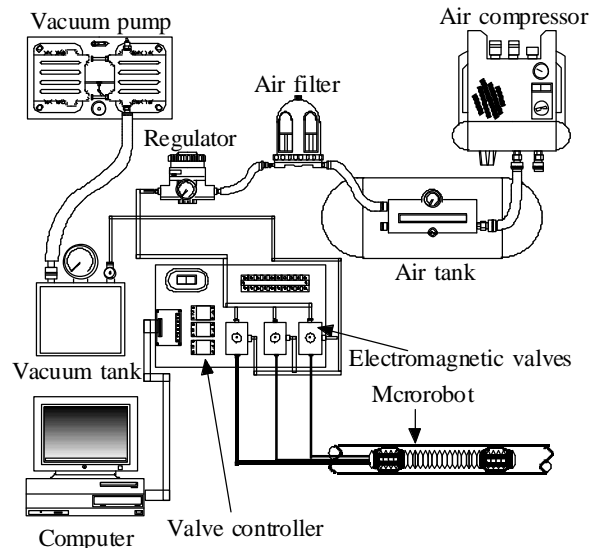


Fig. 3 Experimental apparatus

pneumatic pressure in the stretching motion ($=t_1$). The sum of t_1 and t_2 is called as the cycle time ($=T$).

We make a time difference of $t_1/2$ in the pneumatic supplying time among the front friction braking mechanism, the central moving element and the rear friction braking mechanism. The moving principle of microrobot is shown in Fig. 5, when the pneumatic and vacuum pressure are supplied as shown in Fig. 4.

Step 0: At initial, all the bellows are shrinking by the vacuum pressure. The bulging friction sheets of the front and rear friction braking mechanisms are at the condition of the braking and holds the flexible pipe.

Step 1: The pneumatic pressure is fed to the front friction braking mechanism and the braking is free.

Step 2: The pneumatic pressure is fed to the central moving element and the microrobot is stretching. Then the front part of the microrobot can move to the forward direction, because the rear friction braking mechanism is still at the condition of the braking and holds the flexible pipe.

Step 3: The pneumatic pressure is fed to the rear friction braking mechanism and the braking is free. At the same time, the vacuum pressure is fed to the front friction braking mechanism and it is at the condition of the braking.

Step 4: The vacuum pressure is fed to the central moving element and the microrobot is shrinking. Then the rear part of the microrobot can move to the forward direction, because the braking of the rear friction braking mechanism is free.

Step 5: All the bellows are shrunk by the vacuum pressure. The bulging friction sheets of the front and rear friction braking mechanisms are in the condition of braking and hold the intestine. It is same as the initial condition and one cycle is over. The microrobot moves the stretching displacement of the moving element. Consequently the speed is shown by (stretching displacement) / (cycle time).

5. Experiments

5.1 Measurement of friction force

The relationship between the pressure in a bellows and friction force is shown in Fig. 6. The experiment had done using the pig's small intestine. The pressure in bellows was changed from 0 MPa to -0.08 MPa. Friction force had been measured using the force gauge. When the pressure of the bellows was -0.08 MPa, maximum friction force of 0.8 N was confirmed.

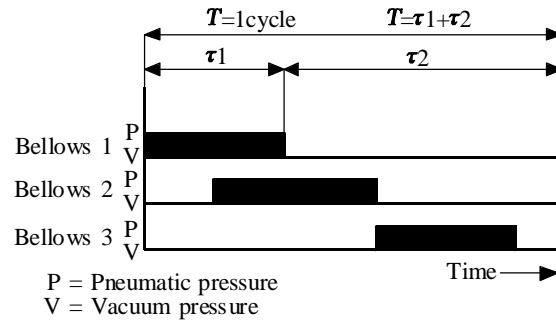


Fig. 4 Time chart of the pneumatic and vacuum pressures for the each bellows

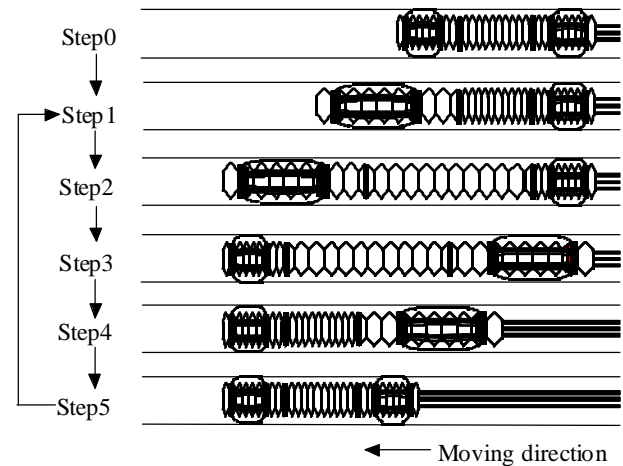


Fig. 5 Moving principle of microrobot

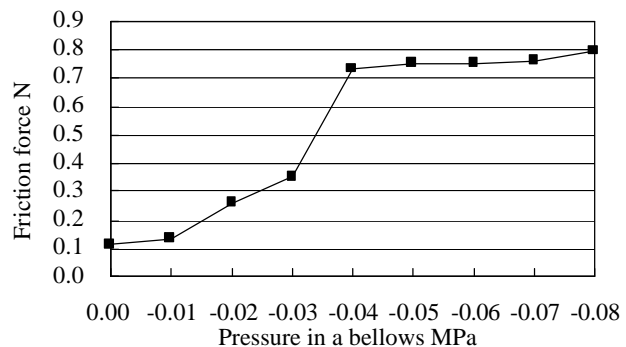


Fig. 6 Relationship between the pressure in a bellows and friction force

5.2 Measurement of the moving speed

We measured the traction force of the microrobot supplying the pneumatic pressure of 0.08 MPa and the vacuum pressure of -0.08 MPa. We chose that the supplying time of the pneumatic pressure in the stretching motion ($=t_1$) is 0.35 seconds. The supplying time of the vacuum pressure in the shrinking motion ($=t_2$) was 0.7 seconds. Relationship between the load and the moving speed is shown in Fig. 7. The microrobot was confirmed to generating the maximum traction force of 0.3 N and the moving speed of 12 mm/s.

5.3 Moving experiment of the curving pipe

The curving pipe of pig's small intestine for moving experiment is shown in Fig. 8. The small intestine is curving pipe that 181 mm of curvature radius, 27 mm of outer diameter, 1190 mm long. The pneumatic pressure of 0.08 MPa and vacuum pressure of -0.08 MPa were taken the cycle time was 1.05 seconds. It confirmed that a moving speed was 20.8 mm/s.

6. Conclusions

(1) We fabricated a new microrobot that can surely move in a flexible pipe like the large intestine. The microrobot consists of two friction braking mechanisms and a moving element. The friction braking mechanisms has a bulging friction sheet which consists of six bulging rubber sheets.

(2) We confirmed by the experiment that the microrobot can move to the forward and backward direction in the pig's small intestine. The moving speed is 12 mm/s and to generated traction force of 0.3 N.

(3) We confirmed by the experiment that the microrobot can move to the curving pipe in the pig's small intestine. The microrobot was confirmed to move at the speed of 20.8 mm/s.

(4) The microrobot may be used to the inspection mobile microrobot for the human large intestine, because the pig's small intestine is very similar to the human large intestine.

Reference

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- [2] M. Ono, E. Arakawa, S. Kyoumine, S. Kato, Fabrication of a Microrobot Movable in a Freely Held Pig's Small Intestine, Proceedings of the 2nd International Conference of EUSPEN, pp. 806-809.

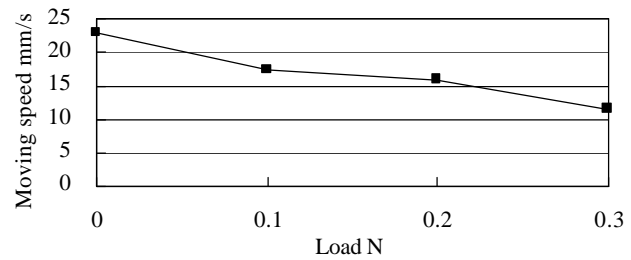


Fig. 7 Relationship between load and moving speed

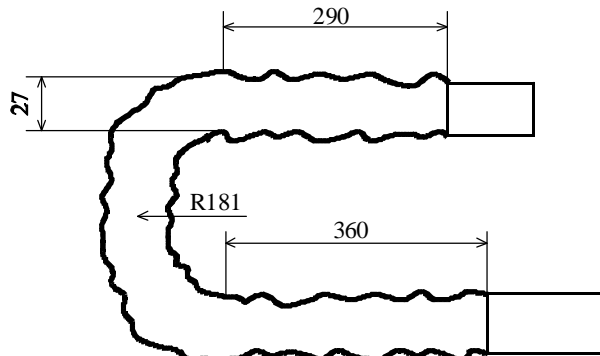


Fig. 8 Curving pipe of pig's small intestine