FABRICATION OF A MICROROBOT MOVABLE IN FREELY HELD PIG’S SMALL INTESTINE

Shigeo KATO\textsuperscript{1}, Manabu ONO\textsuperscript{2}, Akihiro GAKUHARI\textsuperscript{1}, Yuji KUNIYOSHI\textsuperscript{2}, and Toshiaki HAMANO\textsuperscript{1}

\textsuperscript{1}Nippon Institute of Technology, Saitama, Japan
\textsuperscript{2}Tokyo Metropolitan College of Industrial Technology, Tokyo, Japan

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 \cite{1}, \cite{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 a new microrobot that can surely move in the large intestine in the human body. We need a holding work to the radius direction of the flexible intestine and a driving work to the longitudinal direction of the microrobot using the friction force by the holding of the intestine, in order to move surely in the flexible and severely curved intestine, for example, that is a sigmoid. We use six rubber bellows in series. Two outer rubber bellows are provided bulging rubber sheets. These are called as friction braking mechanisms. So, the friction braking mechanisms works as a brake of the microrobot. The center four rubber bellows are arranged as a matrix and is called a driving mechanism. The driving mechanism drives the microrobot by its stretching, shrinking and bending motion. When the rubber bellows of the friction braking mechanism shrinks, six bulging rubber sheets spread to the radius direction and touch the intestine. Then the spread bulging rubber sheets surely hold the intestine. When the rubber bellows of the friction braking mechanism stretches, spreading to the radius direction of the six bulging rubber sheets and touching to the intestine are canceled.

The microrobot was confirmed to move at the speed of 9.5 mm/s in the freely held and severely bended pig’s raw small intestine. In this experiment, it was also confirmed that the microrobot is able to generate the traction force of 3.7 N. The pig’s small intestine is very similar to the human’s large intestine. If the microrobot can move at the speed of 9.5 mm/s in the human’s large intestine, it can move at only five minutes in the round trip of the large intestine.

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 driving mechanism. The two friction braking mechanisms are driven by bellows which are 16 mm in outer diameter,
25 mm long and made of nitrile butyl rubber (NBR). The driving mechanism is driven by four bellows which are arranged as matrix and are 8 mm in outer diameter, 67 mm long and made of NBR. Each bellows is an independent vessel. Six air feeding tubes which are 2.0 mm in outer diameter, 1.2 mm in inner diameter and 1 m long are connected to the two friction braking mechanisms and the moving mechanism. The bulging rubber sheets for two friction braking mechanisms are 5 mm wide, 1.5 mm thick, 25 mm long and made of NBR. The rubber bellows are stretched by pneumatic pressure (positive pressure) and shrank by vacuum pressure (negative pressure). The stretching, shrinking and bending of the rubber bellows are controlled by a computer and electromagnetic valves.

3. ACTION OF THE DRIVING MECHANISM
An action of the driving mechanism is shown in Fig. 2. In the Figure, a straight moving and a moving with the bending are shown. At the case of the straight moving, all four bellows are supplied the negative pressure and the positive pressure in the same timing. At the moving with the bending, two bellows are supplied the positive pressure and two bellows are supplied the negative pressure in the same timing. The driving mechanism can stretch and shrink with the bending as like a bimetal. If three bellows are supplied the positive pressure and a bellows is supplied the negative pressure, the driving mechanism can stretch and shrink with the bending of 45 degrees.

4. EXPERIMENTAL APPARATUS
An experimental apparatus for measuring the characteristics of the microrobot is shown in Fig. 3. A computer controls six electromagnetic valves through a valve controller. Six air feeding tubes are connected from the electromagnetic

V = Negative pressure  
P = Positive pressure

FIGURE 1. Structure of the fabricated microrobot

FIGURE 2. The action of the driving mechanism feeds the positive pressure in order to stretch the bellows.
valves to the two friction braking mechanisms and the moving mechanism of the microrobot.
An air compressor is connected to the entrance ports of the electromagnetic valves and a vacuum pump is connected to the exit ports of the electromagnetic valves and feeds the negative pressure in order to shrink the bellows.

5. EXPERIMENTS

5.1 Measurement of friction force
The relationship between the number of the bulging rubber sheets for friction braking mechanisms and the friction force is shown in Fig. 4. The experiment was done using the pig's small intestine. The pressure in the bellows was -80 kPa. The friction force was measured by the force gage. The friction force is confirmed to increase in the proportion of the number of the bulging rubber sheets. In the case of six sheets, the friction force of 3.7 N is obtained.

5.2 Measurement of bending angle of the moving mechanism
The relationship between the positive pressure in the bellows and bending angle of the moving mechanism is shown in Fig. 5. The positive pressure is supplied to two bellows and zero pressure is supplied to another two bellows. The bending angle is confirmed to increase in the proportion of the positive pressure in the bellows. In the case of the positive pressure of 30 kPa, the bending angle of 180 degrees is obtained.

5.3 Measurement diameter of the bulging braking sheets
The relationship between the pressure in the bellows and diameter of the bulging braking sheets is shown in Fig. 6. The diameter of the bulging braking sheets is less than 26 mm at the pressure more than 20 kPa. Then, the braking
action of the bulging braking sheets is canceled at the pressure more than 20 kPa, because the average diameter of the pig’s small intestine.

5.4 Moving experiment in the freely held pig’s small intestine
The freely held pig’s small intestine for moving experiment is shown in Fig. 7. The microrobot was confirmed to move at the speed of 9.5 mm/s in the freely held and severely bended pig’s raw small intestine.

6. CONCLUSIONS
1. We fabricated a new microrobot that can move in the freely held and severely bended pig’s raw small intestine. The microrobot consists of two friction braking mechanisms and a moving mechanism. The friction braking mechanism has bulging friction sheets.

2. The driving mechanism, in which four rubber bellows are arranged as a matrix, drives the microrobot by its stretching, shrinking and bending motion.

3. We confirmed by the experiment that the microrobot can move in the freely held and severely bended pig’s raw small intestine. The moving speed is 9.5 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. If the microrobot can move at the speed of 9.5 mm/s in the human’s large intestine, it can move at only five minutes in the round trip of the large intestine.

REFERENCES