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Design of a Novel Drug-Delivery Capsule Robot

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***Abstract*– This paper proposes a modular capsule robot. It can move actively. The main robot is responsible for collecting images to determine the location of the lesion, and the auxiliary robot is used to release medicine to the location of the lesion. Their 3D models were constructed by SolidWorks and printed by 3D printers. In addition, it also carefully presents the robot's drive system, motion control theory, and the principle of drug delivery. In the magnetic field generated by the three-axis Helmholtz coil, the robot's motion characteristics are tested, and the relationship curve between the robot's speed and the current frequency is simulated. The modular experiment of two robots also has been verified many times.**

***Index Terms* - drug delivery module, wireless capsule robot, Helmholtz coils**

I. Introduction

Digestive system diseases are the most common, with a higher incidence of hospitalizations, and they are also the most dangerous diseases[1]. According to WHO statistics (2016), there are 120 million patients with severe gastrointestinal diseases in China, and more than 10 million people die from gastrointestinal diseases in the world every year. More than 4 million people die from diarrhea alone, and the incidence of chronic gastritis is as high as 30 %. The "2015 China Cancer Data Report" shows that there are 679,000 new cases of gastric cancer and 498,000 deaths each year in my country. On average, nearly 12,000 are diagnosed with cancer every day, of which stomach, and colon cancer account for nearly 40%. Data shows that "56.18% of Internet users have stomach pains, and more than 85% of Chinese people have had gastrointestinal problems." Globally, nearly half of the new cases of gastric cancer and deaths occurred in China[2].

The research of capsule endoscopy is mainly divided into two aspects. On the one hand, it is the research on the active motion control of the capsule robot, mainly from the energy supply mode and driving mode[3]. The energy supply mode of the capsule robot can be divided into electric energy driving and magnetic energy driving[4]. The electric energy-driven capsule robot mainly relies on the built-in power supply or wireless power supply device of the capsule robot, and the magnetic energy-driven capsule robot mainly relies on the coupling effect of the external magnetic field and the built-in magnet of the capsule robot[5]. According to relevant literature records, by comparing 98 patients' wireless capsule endoscope with traditional gastroscopy, the matching rate is as high as 72.5%[6]. The experimental results show that magnetic drive is a safe and reliable method to control the active movement of the robot[7]. The research on the driving mode of capsule robots can be divided into crawling robots, spherical robots, and spiral robots[8].

Another aspect is the research on the diagnosis and treatment function of the capsule robot. In order to use the capsule endoscope for more accurate diagnosis, research scholars at home and abroad have studied the functions of capsule robots such as biopsy, targeted drug delivery, environmental detection, hemostasis, and anchoring[9]. However, most capsule robots have a single function and can only perform a specific function, and do not combine diagnostic and therapeutic functions, which limits the clinical application of capsule robots[10].

The expected capsule robot should integrate gastrointestinal detection and treatment. When it is swallowed into the gastrointestinal tract, the capsule robot can be controlled by an external controller to make the capsule robot move and change its posture autonomously[11]. At the same time, the integrated image acquisition in the robot. The module can collect images in the gastrointestinal tract and transmits them to an external computer for medical personnel to analyze and diagnose[12]. Finally, the capsule robot is used to collect living tissues and deliver targeted drugs. However, at present, the internal space of the capsule robot is not enough to accommodate devices such as micro-manipulators and sensors. Therefore, the key technology of the wireless micro-channel capsule robot needs to be improved[13].

At present, the research on the micro-tube capsule robot is mainly conducted in two aspects: one is to design a new structure to improve the effective movement of the robot through the new structure, change the robot's posture in the human intestines and stomach, reduce the damage of the mechanical structure to the digestive tract, and improve the robot's performance[14]. The adaptability of the environment; the other is to use MEMS technology to change the internal structure of the robot, its functions have also been increased a lot, so that it can realize the functions of image acquisition, precise positioning, targeted drug delivery, living body detection, etc. Robots have more use value[15].

In this paper, a new type of drug delivery capsule robot is designed, its movement principle is to rely on the rotation of the propeller to obtain forward and backward thrust[16]. In addition, its drug delivery device is mainly composed of two radially magnetized magnets. When the drug is not administered, the two magnets are attracted together under the action of attractive force[17]. When it reaches the designated position, we need it to apply the medicine[18]. Let one of the magnets rotate. Under the action of the repulsive force, the two magnets will quickly repel, so that the magnets will

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squeeze the potion in the potion, and the potion will be sprayed out.

II. Design of a Drug Delivery Capsule Robot

The capsules that have been used in the market now generally only have the function of shooting, but do not have the functions of medicine, biopsy and other medical treatment. In the research, a robot module is designed so that it can administer medicine to the diseased part, and it can spray the medicine in the medicine warehouse to the designated position more accurately.

A. The Model of Drug Delivery

The drug delivery principle of this drug delivery robot has to be long and easy to understand, which is to use the repulsive force between the magnets to squeeze the medicine in the drug store from the drug delivery port. Its active movement needs to rely on small magnets to drive the propeller to rotate, as shown in Fig.1.

The drug delivery module includes two radially magnetized magnets, two small springs, two small spacers and a drug delivery tube, as shown in Fig.2.The internal pipe of the drug delivery tube is curved, as shown in Fig.3. During the spraying of the medicine, energy loss can be avoided, ensuring that the medicine has sufficient power potential to reach the location of the lesion.

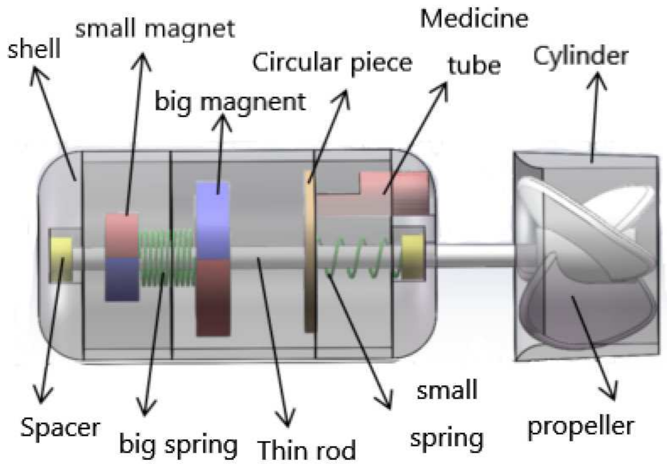


Fig. 1 The Internal structure of the drug delivery robot

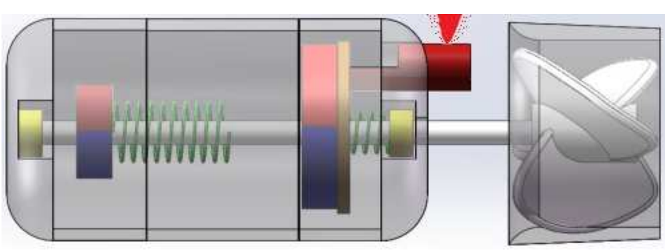


Fig.2 The diagram of the dispensing state of the drug delivery robot

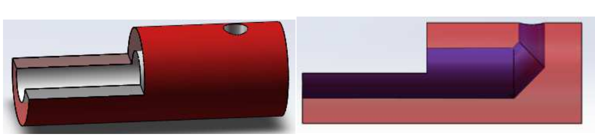
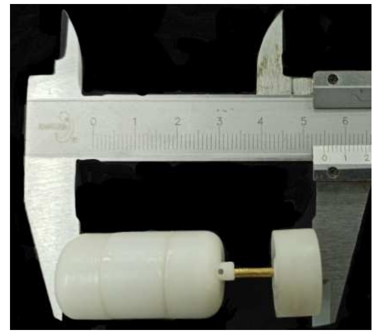


Fig.3 The 3D Model of drug delivery tube

(a) The parts drawing of the robot.

(b) The dismantling diagram of the robot



(c) The appearance of the robot

Fig.4. The 3D printing diagram of the designed robot

B. The Production of Robots

The size of the drug delivery capsule robot is relatively small, its total length is 51mm, the diameter length is 19mm, and the diameter length of the medicine outlet is 1mm.

Its main structure is printed by a 3D printer. First, the SolidWorks software can draw its parts diagram, and then the parts are printed out separately, and finally they are assembled. Among them, the hard copper wire with a diameter of 2mm is used to connect the central axis of the robot.

III. Introduction of the Drug Release Process

A. The Mechanism of Drug Release

The function of drug release is based on the principle of magnetic polarity. In the design of this paper, the small magnet and the thin rod are fixed together, and the large magnet is not fixed, as illustrated in Fig.4, so it can be rotated at will, or along the thin rod pole run. However, for the two magnets that are attracted together, the torque of the magnet's rotation needs to be calculated, and there is a certain relationship between the torque and the distance between the magnets.

The attraction or repulsion between two non-contact magnets has a certain law. According to the basic equation of the magnetic circuit, the following formula can be obtained, as shown in Fig.4:

$$F_a = F_r = \frac{1.5}{1+aL_q}\left(\frac{B_q}{4865}\right)^2 A_q \tag{1}$$

Among them, a is not a fixed value, and its range is generally between 3 and 5; A_q , L_q , B_q can respectively represent the magnetic field area of the permanent magnet, the gap between the two permanent magnets, and the magnetization intensity;Adding an upward magnetic field to the magnet, as shown in Fig.5. The force applied in this magnetic field is that of a permanent magnet, which is shown in equation (2) (3).

In this huge magnetic field, the magnet appears very small in the magnetic field, which fully meets the requirement that it can be used as a magnetic dipole, and a similar potential energy can be obtained:

$$\mathrm{U} = -\mathrm{m} \cdot \mathrm{B} \tag{2}$$

Where, B is the magnetic induction intensity，and m can represent the magnetic torque of this magnet. Therefore, in the magnetic field, the force of the magnet is:

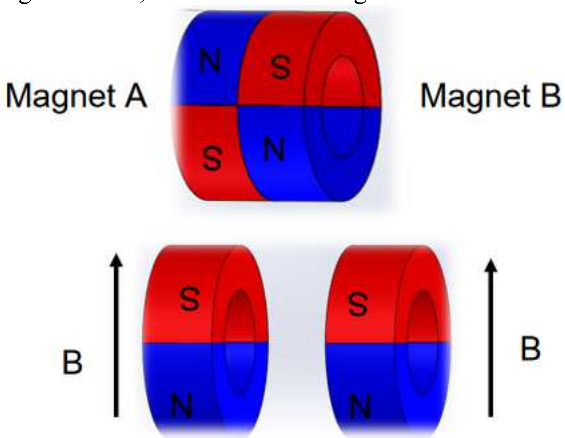


Fig.5. The process of driving principles.

$$\mathrm{F} = -\nabla\mathrm{U} = \nabla(m \cdot B) = \mathrm{m} \times (\nabla \times \mathrm{B}) + (m \cdot \nabla)\mathrm{B} \tag{3}$$

In Figure 5, the force between magnet A and B is so small compared to the force of the magnetic field, so the magnets can be rotated and separated. The magnitude of the repulsive force between magnet A and B can be calculated by equation (1).

B. *Control Principle of Precise Application*

There is a large enough space inside the robot. There is a long shaft inside the robot, and two radially magnetized magnets are passed through the long shaft. The magnet a on one side of the robot head is fixed to the long shaft, and the magnet b on the side can rotate freely around the long axis, and can also move forward and backward along the long axis. The magnetic field that is produced by the coil connected to the alternating current can make the two magnets drive the robot to continuously rotate, and then make the robot move. The direction of the magnetic field that is produced by the coil with direct current is fixed, which will cause the two magnets to be in the same direction, and the medicine will be sprayed out due to the repulsive force.

The application process of the drug delivery robot and the attraction and repulsion process between the two magnets are shown in Figure 6. Here are all their steps:

(1) Due to the attraction, the two magnets are tightly attracted together.
(2) When a directional magnetic field appears, the direction of the magnetic force of the two magnets will be consistent with the direction of the magnetic field, which will generate repulsive force.
(3) Adjust the medicine outlet and the position of the lesion to the same direction.
(4) After the drug is administered, the directional magnetic field is replaced with a rotating magnetic field.
(5) The two magnets are attracted together again due to the attraction.
(6) A complete drug delivery process is completed.

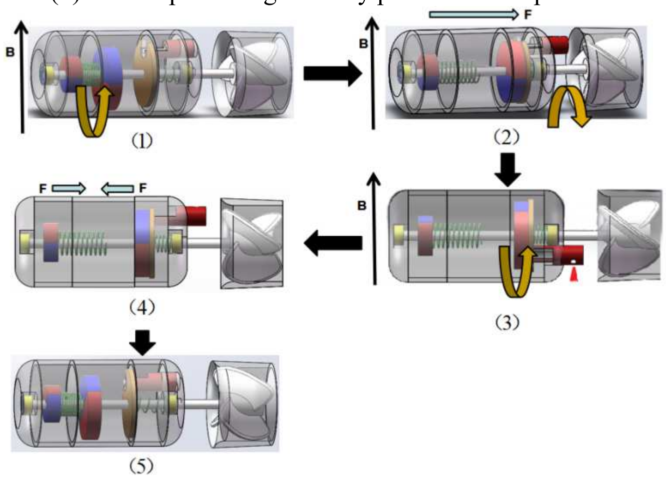


Fig.6. The robot's drug release steps

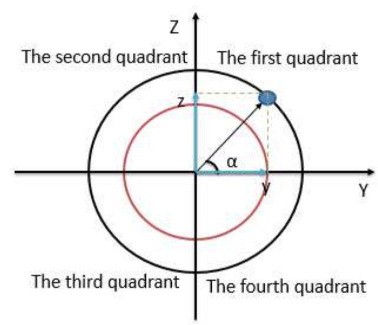


Fig.7A Cartesian coordinate system at the center of the pipe cross section

$$H_x = 6.6 \times I_x(Gs) \tag{4}$$

After conducting multiple magnetic field tests on the Y coil, it is found that the magnetic field and current have the following formulas:

$$H_y = 7.4 \times I_y(Gs) \tag{5}$$

The same as, after conducting multiple magnetic field tests on the Z coil, it is found that the magnetic field and current have the following formulas:

$$H_z = 7.2 \times I_z(Gs) \tag{6}$$

H is considered to be the magnetic field strength.

Theoretically, we must rotate the drug delivery port to any angle. We use the cross section of the glass tube as the reference plane and the center of the circular cross section to establish a rectangular coordinate system. There is a certain angle between the position of the lesion and the positive direction of the Y axis, as shown in Fig.6.We can get the field strength in Y and Z directions by combining equations (7) and (8) with the vector law.

$$H_y = \mathrm{W}\cos\alpha \tag{7}$$

$$H_z = \mathrm{W}\sin\alpha \tag{8}$$

Through many experiments, we finally found that W is the minimum field strength that can separate the two magnets.

W=34.7Gs.

The exact value of the current to be used can be calculated by formulas (5)-(8).

$$I_y = \frac{H_y}{7.4} = \frac{\mathrm{W}\cos\alpha}{7.4} \tag{9}$$

$$I_z = \frac{H_z}{7.2} = \frac{\mathrm{W}\sin\alpha}{7.2} \tag{10}$$

Finally, we can adjust the current to control the rotation angle of the drug delivery port. For other quadrants, the same method can also be used.

IV. Experiments and Results

In the following experiment, the magnetic field is generated by a three-axis Helmholtz coil after it is energized. The capsule robot first needs to be placed in a glass tube similar to the intestine for experiment.

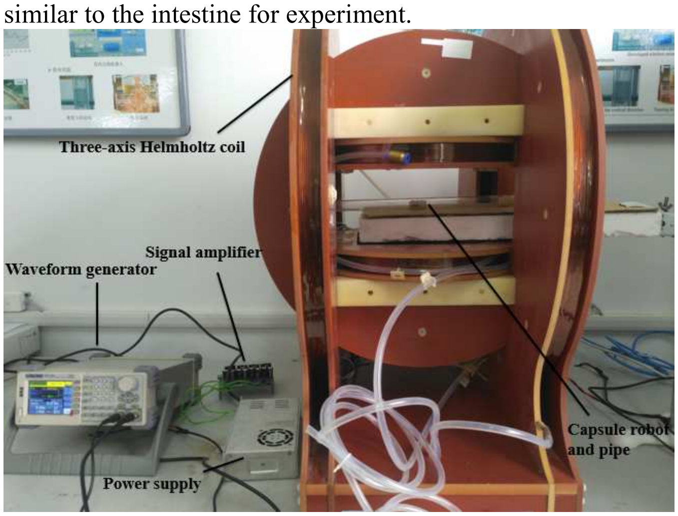


Fig. 8 Physical map of the experimental platform

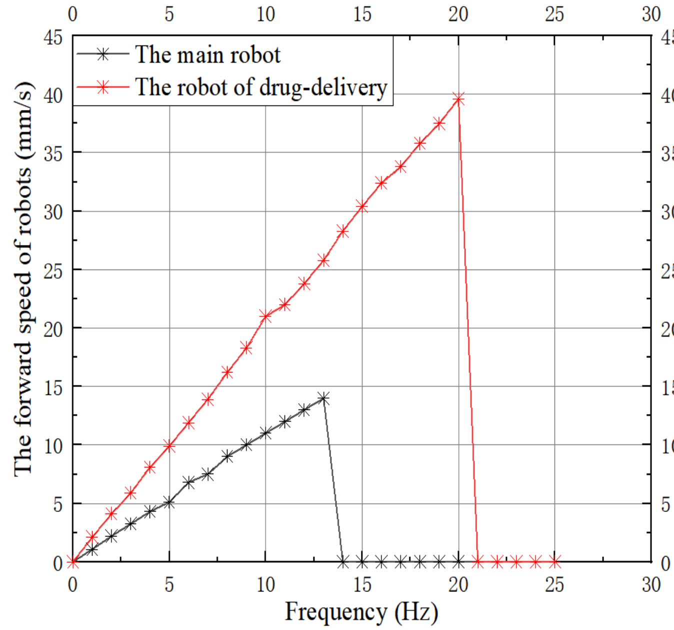
A. Movement Experiments

The experimental platform we used is shown in Figure 8. In this experiment, we only conducted experiments and analyses on the movement of the robot in one of the axial directions.

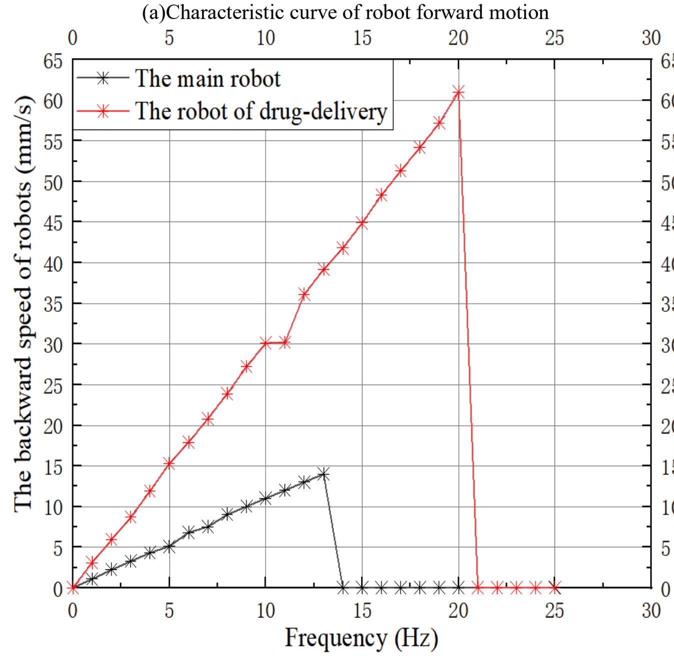
The experiment conducted in this paper is mainly the movement experiment of the robot forward and backward. The current frequency range of the alternating current applied to the energized coil is from 0 to 25HZ, and the speed of the robot is accurately measured every 1HZ. Figure 9 shows that when the frequency increases to a certain value, the speed of the robot will drop to 0. This is because the current frequency is too high, which will cause the robot to fail to keep up with the rotation frequency of the magnetic field. We call this frequency the cutoff frequency.

B. Drug Release Experiment of Robots

Finally, we conducted many experiments by using the robot and verify that the robot can detect the location of the lesion and apply medicine to the location of the lesion. The experimental environment and the water flow in the glass tube is static, so that we can see the whole experiment process more clearly.



(a)Characteristic curve of robot forward motion

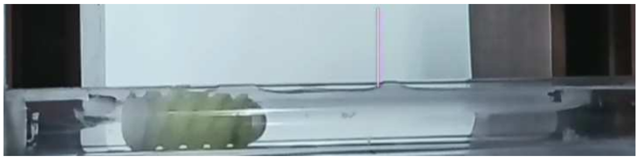


(b)Characteristic curve of robot reverse motion

Fig. 9The relationship between the speed of the robot and the frequency of the current in the coil

For convenience, we call the main robot as robot M and the drug delivery robot D. At the beginning of the experiment, robot M is on the side of the pipeline, as shown in Figure 10(a). Robot M first reaches the designated position, as is shown in Figure 10(b). Then the robot D approaches the robot M until they are combined, and they begin to move forward together until the medicine outlet locks the lesion position, as shown in Figure 10(f). The robot D starts to administer the drug, and continues to move forward after the drug is completed.

The pathological position of the intestine is the cavity wall of the intestine, we set up a rectangular coordinate system on the cross section of the catheter in the center of the catheter.

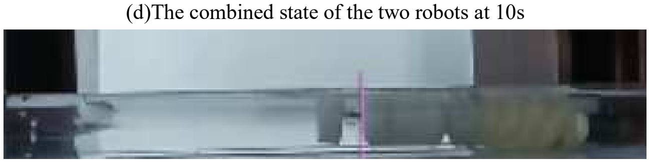


(a)The motion state at 0s.

(b It moves to the target position at 3s.

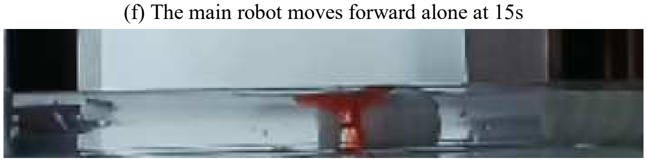
(c)The combined state of the two robots at 7s

(d)The combined state of the two robots at 10s



(e) The medicine outlet reached the location of the lesion at 13s

(f) The main robot moves forward alone at 15s



(g) The state when the drug is released at 18s

(h) The state after the drug release is completed at 21s

Fig. 10 The snapshots of the drug release process

Experiments were carried out at 5 different angles, and the positive direction of the Y axis was 0, 45, 90, 135, and 180respectively. Moreover, in theory, we can achieve drug release from any angle in the range of 0-360.

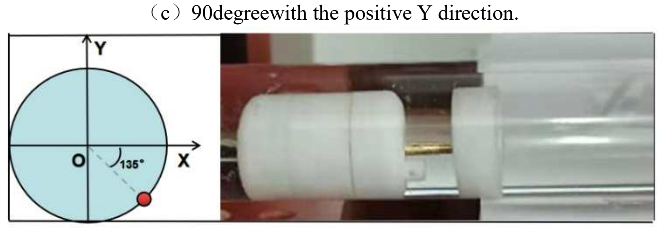
V. CONCLUSION

This paper proposed a modular capsule robot. The main robot is used to collect images and to look for the location of the lesion, and the auxiliary robot can release medicine to the location of the lesion. Their 3D models are constructed by SolidWorks and printed by 3D printers.

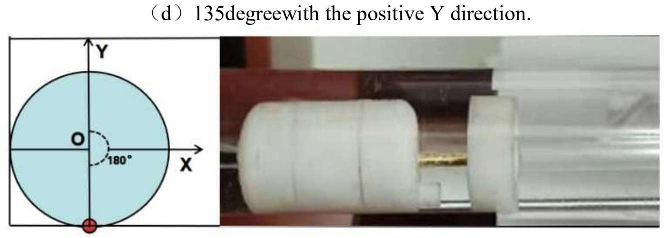
（a）0degree with the positive Y direction.

（b）45degreewith the positive Y direction.

（c）90degreewith the positive Y direction.



（d）135degreewith the positive Y direction.



（e）180degreewith the positive Y direction.

Fig.11 Snapshots of different angles of drug release in the pipeline

In the magnetic field generated by the three-axis Helmholtz coil, the robot's motion characteristics are tested many times. And the relationship curve between the robot's speed and the current frequency is obtained and discussed.

ACKNOWLEDGMENTS

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