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Conceptual Design of a Novel Magnetically Actuated Hybrid Microrobot

Qiang Fu[*1*2], Shuxiang Guo[*1*3], Jian Guo[*1],

[*1]Tianjin Key Laboratory for Control Theory & Application in Complicated Systems and Biomedical Robot Laboratory
Tianjin University of Technology,
Binshui Xidao 391, Tianjin, China
Fuqiang6369@hotmail.com

[*2]Graduate School of Engineering, Kagawa University
Takamatsu,Kagawa 761-0396, Japan
Fuqiang6369@hotmail.com

[*3]Department of Intelligent Mechanical Systems Engineering, Kagawa University,
Takamatsu, Kagawa 761-0396, Japan
guoshuxiang@hotmail.com
*Corresponding author

Abstract –**In this paper, to deal with the performance of the medical microrobot in fluid condition, we proposed a novel type of magnetically actuated hybrid microrobot. The magnetically actuated hybrid microrobot has characteristics of controllability and multi-function. It has a simple structure, a simple control strategy with a rotational magnetic field and good dynamic in fluid. The magnetically actuated hybrid microrobot is composed of microrobot body with a screw jet motion, microrobot leg with paddling motion and microrobot tail with fin motion. We designed a rotational magnetic field and an alternate magnetic field to realize the screw jet motion, paddling motion and fin motion. We carried out the evaluating experiments for screw jet motion and moving motion in a pipe. The experimental results indicated that the magnetically actuated hybrid microrobot has a good performance on flexibility.**

Index Terms – Magnetically actuated hybrid microrobot; Screw jet motion; Paddling motion; Fin motion; Rotational magnetic field; Alternate magnetic field.

I. INTRODUCTION

Magnetically actuated microrobot is used widely in the medical applications, which is as a kind of diagnostic tool [1]-[10]. The magnetically actuated microrobots are safe reliable and can carry deeply to some narrow areas within the tissue of living in the human body, such as small intestine. And they have many potential applications in the field of medical engineering. For example, they may be used for microsurgery in blood vessels, which is expected to become an increasingly widely adopted medical procedure in the near future. With advances in precision processing technology, several types of magnetically actuated microrobots have been developed for various applications and further progress in this field [11-13]. Meanwhile, different kinds of control strategy is used to drive the magnetically microrobots [14-17]. For example, the permanent magnet as an actuator is fitted inside the magnetically microrobot. The electromagnetic coils as an actuator is fitted inside the magnetically microrobot.

Compared with the traditional medical microrobot which move by peristalsis [18], the magnetically microrobot solved the problem – the magnetically microrobot has the flexible motion and can arrive at the target to finish some functions. In other word, we can control the orientation and position of the microrobot in medical application.

Guo et al. developed many magnetically microrobot which control by electromagnetic actuation (EMA) system [19-24], as shown in Fig. 1. They can use the basic motion (e.g. forward motion, backward motion, stop motion) to move the target in pipe. The fish-like microrobot inspired by the movement of the fish is controlled by a MTX sensor in natural frequency. Meanwhile, other researchers developed different kinds of magnetically microrobot. B. J. Nelson developed an EMA system which consists of Helmholtz and Maxwell coils. The microrobot has a flexible motion in the EMA system [25]. However, movement of the microrobots is limited due to their structure. In this paper, we proposed a magnetically actuated hybrid microrobot. Hybrid motion can be controlled separated without any interference, due to our proposed screw jet structure. We can change its motions to realize multi-DOFs movement and flexibility motion in the pipe.

This paper is organized as follows. Firstly, we introduce the electromagnetic actuation system. Secondly, we proposed a conceptual design of a magnetically actuated hybrid microrobot. And then, we built a propulsive force model for the hybrid microrobot and explain its movement mechanism. Thirdly, based on the propulsive model, we evaluated the performance with different parameters. The final part of the paper presents our conclusions.

II. ELECTROMAGNETIC ACTUATION SYSTEM

A. Electromagnetic actuation system

Our group developed various electromagnetic actuation systems in the past decade [26-28]. It is used to control the

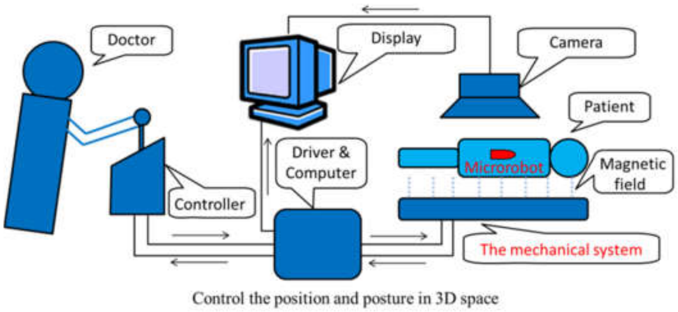
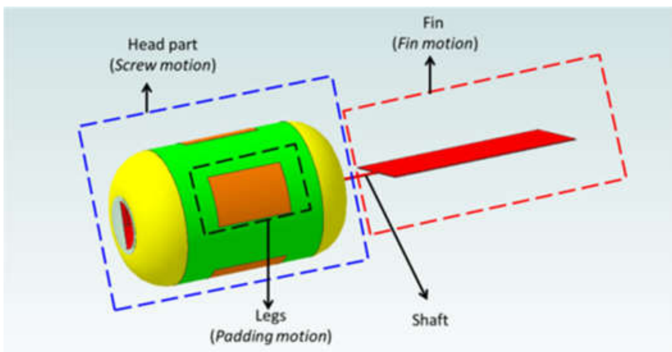
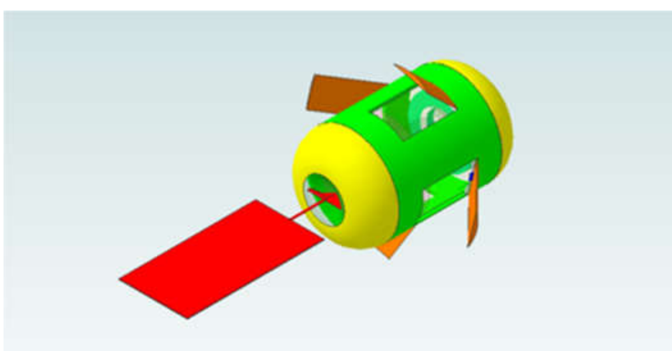


Fig. 1 Electromagnetic actuation system (EMA system)



(a)Hybrid microrobot with leg close



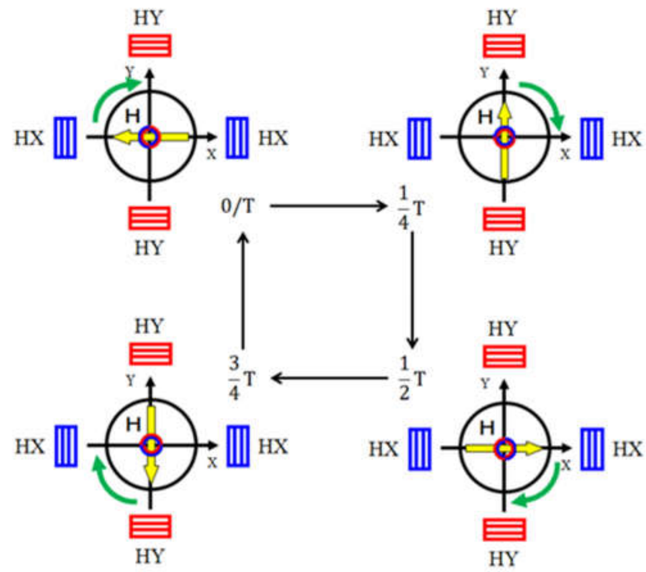
(b) Hybrid microrobot with leg open

Fig. 2 Conceptual design of the magnetically actuated hybrid microrobot with screw jet motion, paddling motion and fin motion

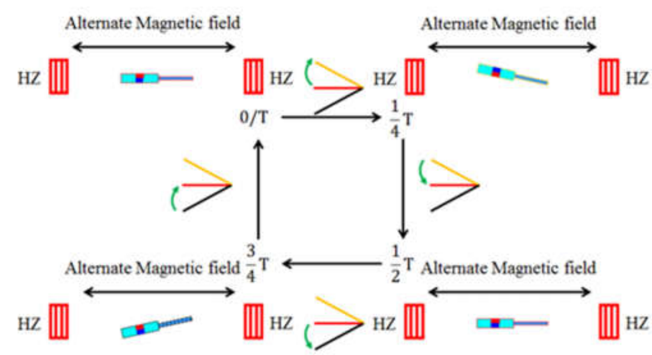
robot, the magnet as an actuator inside the robot body. One of the electromagnetic actuation systems is shown in the Fig.1. The type of magnetic microrobot is controlled by an external coils or magnet, which is used to generated the magnetic force and magnetic torque in the work space. While watching the display to obtain the information, such as the position of the microrobot and posture of the microrobot in the GI tract, the operator operate the microrobot to move to the target and realize the function, such as, drug delivery, endoscope, and so on.

B. Magnetic force and magnetic torque

While a magnet inside an external magnetic field, the magnetic torque is provide by the magnetic field. Due to the magnetic torque, the magnetically microrobot can obtain the rotational motion and alternate motion. In our research, the



(a) Rotational motion



(b) Alternate motion

Fig.3 Principle of rotational motion and alternate motion

3axes Helmholtz coils is used to generate the magnetic field, the magnetic torque is given by the equation (1):

$$T = \mathrm{VM} \times B \tag{1}$$

where, V is the volume of the magnet, M is the magnetization of the magnet.

III. Conceptual Design of Magnetically Actuated Hybrid Microrobot

A. Magnetically actuated hybrid microrobot

Various magnetically actuated microrobots have been developed. They hold some advantages, such as flexible motion, small size and so on. It is important how to arrive the target and realized multi-motions, not simplex motion. According to these previous researches, we proposed a magnetically actuated microrobot with hybrid motion, screw jet motion, paddling motion and fin motion, as shown in Fig. 2. The hybrid microrobot composed of three parts, microrobot body, microrobot tail and microrobot leg. The microrobot body has a screw jet motion to realize the basic motion, forward motion and backward motion [26-28]. In previous

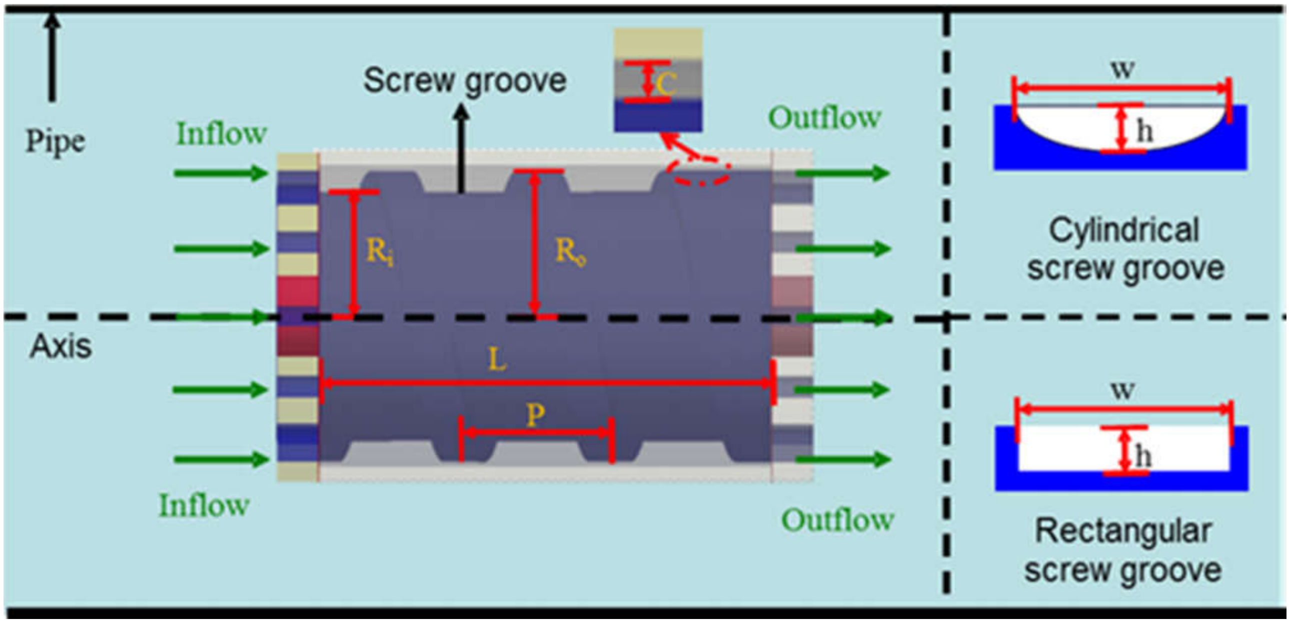


Fig. 4 Propulsive force model

research, we realized the rotational motion by changing the rotational direction of the magnetic field. For example, the magnetically microrobot move forwardly/backwardly with the rotational direction of the magnetic field is clockwise/counter-clockwise, as show in Fig. 3 (a). Fig.3 (b) shows the principle of alternate motion according to changing the alternate magnetic field.

B. Propulsive force model

Fig. 4 shows the propulsive force model of screw jet motion. While the magnetically microrobot moves inside the liquid, the liquid pass the microrobot from one end of the microrobot to other end of the microrobot at the same time. Based on the hydrodynamics, the liquid volume of the inflow area is equal to liquid volume of the outflow area for unit time given by equations (2), (3) and (4):

$$Q = A_1V_1 = A_2V_2 \tag{2}$$

$$F_p = \rho Q v_2 = \rho Q \times \frac{Q}{A_2} = \rho \frac{Q^2}{A_2} \tag{3}$$

$$F_p = \frac{\rho}{4} \frac{Q_{cyc}{}^2 \omega^2}{\pi^2 A_2} \tag{4}$$

where, Q is liquid volume at unit time, V_1 is the inflow velocity of the area A_1. V_2 is the outflow velocity of the area A_2. F_p is the propulsive force. ρ is the density of liquid. ω is the angle of the angular speed of the microrobot

IV. IMULATION AND EXPERIMENTAL RESULTS

According to the discussion of the session III, two kind of screw grooves (cylindrical screw groove and a rectangular screw groove) with different parameters ,as shown in Table I, are evaluated the performance of the magnetically with screw jet motion. In this paper, we assumed the dimensions to be outer diameter = 13 mm and the inner diameter= 11 mm for the inner radius, respectively. The size of the screw and the length of the body is the same.

Table I Simulation parameters of the cylindrical screw groove and a rectangular screw groove

	Cylindrical groove	Rectangular groove
Outer diameter	13mm	13mm
Inner diameter	11mm	11mm
Pitch	5	5
Length	30 mm	30 mm
h	2mm	2mm
w	4mm	4mm

Fig. 5 shows the compared results between the cylindrical screw groove and a rectangular screw groove. From the simulation results, we can know that the rectangular screw groove type microrobot generated a larger propulsive force than the cylindrical screw groove type microrobot at the same rotational speed. The relationship between the rotational speed and the height of the screw groove with different width of the screw groove is shown in Fig. 6 and Fig. 7. If the microrobot generated a propulsive force F_p = 9 mN, the pitch of the microrobot is 5, the microrobot with w=2.0mm needs a lower rotational speed than the microrobot with w=1.0. Also the microrobot with h=2.0mm needs a lower rotational speed than the microrobot with h= 1.0 in order to generate the same propulsive force. Fig. 7 shows the simulation results of the microrobot generates the propulsive force is 10 mN with different parameters.

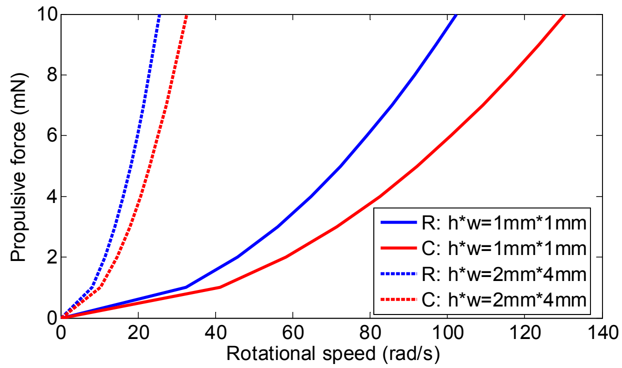


Fig. 5 Compared results with different screw groove, R means rectangular screw groove, C means cylindrical screw groove.

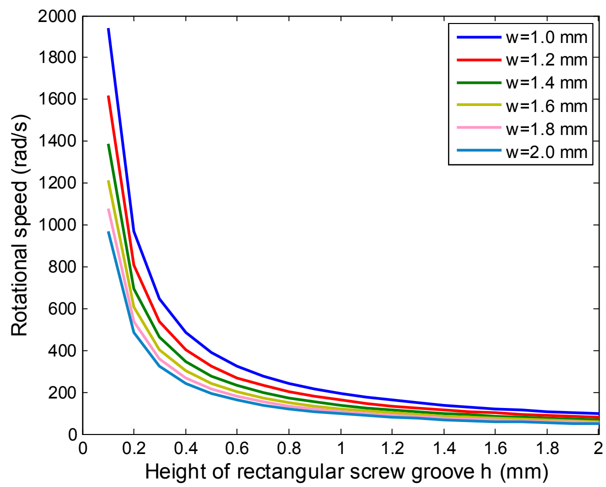


Fig. 6 Simulation results of rotational speed with different parameters of screw groove (P=9mN pitch=5mm)

We used our proposed electromagnetic actuation system to realize the basic motion. In this experiment, a controller is used to control the signal for proving the 3 axes Helmholtz coils, and using our proposed user interface to control the direction of the microrobot in the pipe. Fig. 8 shows the experimental result, which is moving the 45o with the X axis. By adjusting the magnetic changing frequency, the microrobot realized the speed variation.

V. Conclusions

In this paper, we proposed a conceptual design of the magnetically actuated hybrid microrobot. The magnetically actuated hybrid microrobot is driven by a electromagnetic actuation system, which generates a rotational magnetic field and alternate magnetic field. We made and evaluated the performance of the screw jet motion to optimize the performance. Based on the propulsive model, we compared the performance with different parameters, for example, different width of the screw groove and height of the screw groove in the same diameters of the microrobot, pitch and length of the microrobot. The experimental results indicated that the microrobot realized the flexible motion in the pipe, by adjusting the changing magnetic frequency. In the future, we

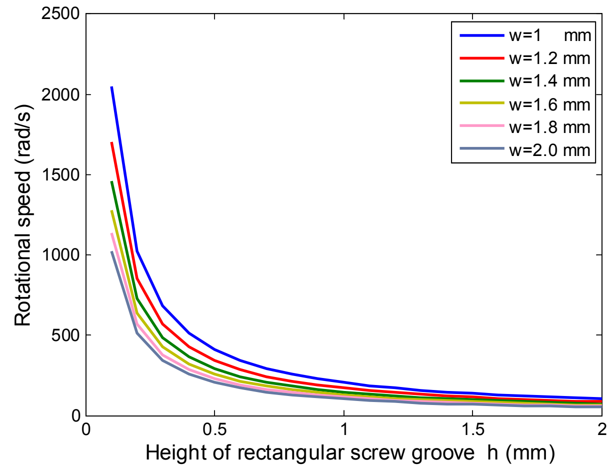


Fig. 7 Simulation results of rotational speed with different parameters of screw groove (P=10mN pitch=5mm)

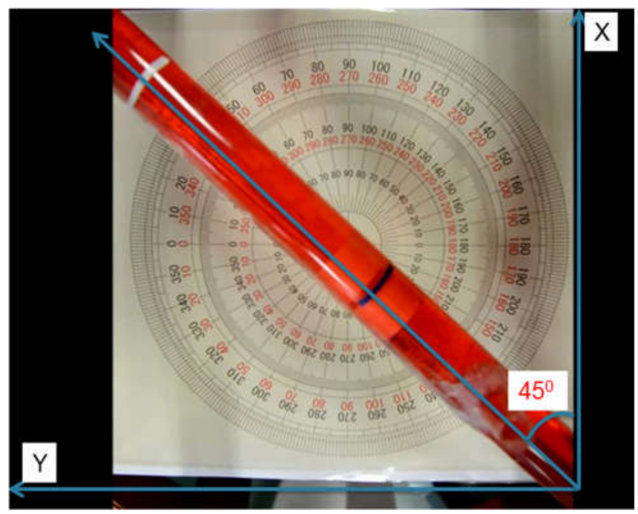


Fig. 8 Experimental results

evaluate the performance of magnetically actuated microrobot with different parameters.

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