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# Performance Evaluation of a Magnetically Actuated Microrobot with Screw Jet motion in Vertical Plane

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***Abstract* – Various kinds of magnetically actuated microrobot have been proposed to deal with the performance evaluation in medical application and industry application. In this paper, we discuss the mechanical structure design and the control method for obtaining the optimal performance of the microrobot in fluid condition. We analyzed the magnetic field to obtain the relationship between the magnetic flux density and the region of interest in the three-axis Helmholtz coils to adjust the position and posture of the microrobot which is controlled by our proposed magnetic actuation system. This result indicated that the magnetically microrobot has characteristics of multi-functions, controllability, stability.**

***Index Terms –Magnetically microrobot; Mechanical structure design; three-axis Helmholtz coils.***

## I. Introduction

Magnetically actuated microrobot controlled by magnetic field in biomedical applications. The medical safety, loading abilities and an effective propulsive performance are extremely important and challenging [1-16]. Therefore, in this thesis, a multi-module magnetic actuated microrobotic system is proposed. Our proposed microrobotic system includes two parts, microrobots and electromagnetic actuation (EMA) system. The microrobot composes of different module with multi-functional. It is comfortable and easy to swallow by patients, because it can realize the docking and releasing in various environments and has the flexible motion with wireless control.

In previous research, various kinds of microrbot are proposed. Meanwhile many control method are also developed for driving the microrobot in magnetic field [17-25]. Fig. 1 shows the overall control system for the magnetically actuated microrobot in the medical application. The hardware of magnetic actuation system consist of magnetic microrobot as a driven module for achieving some function in region of interest, three axes Helmholtz coils generated the rotational magnetic field for manipulating the magnetic microrobot, and positioning system for measurement the position and posture of the microrobot, while the microrobot works in the region of interest. In addition, the magnetic actuation system also realizes the tele-operation by in internet. And for manipulating the microrobot, an interface is developed with Microsoft Visual Studio 2010, as shown in Fig.2. The user can real-time control the motion of the microrobot in the pipe, such as, forward motion, backward motion and stop motion. Also the speed of the microrobot is adjusted by the interface.

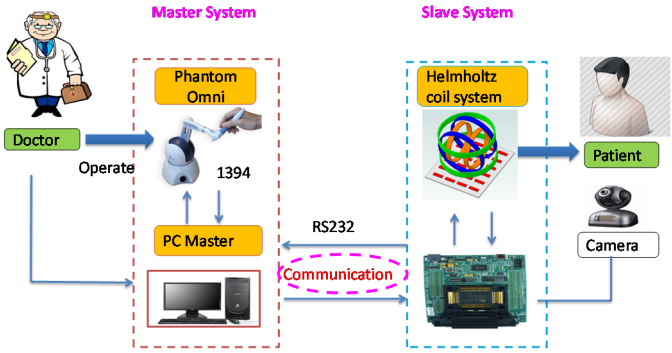



Fig. 1 Overall control system

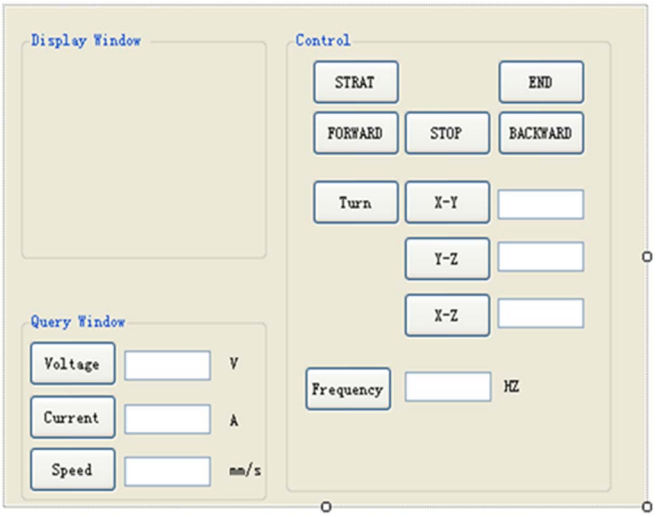



Fig.2 Interface for manipulating the magnetic microrobot

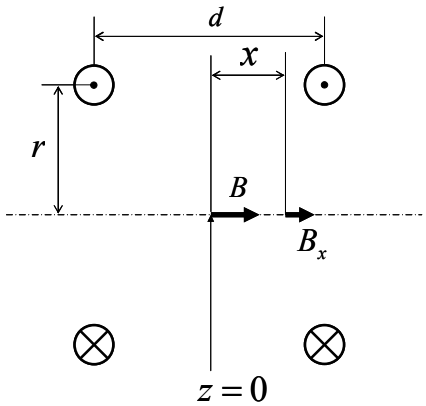



Fig. 3 Model of Helmholtz coils

## II. Working Principle of the Magnetically Actuated Microrobot

In previous research, we proposed a three axes Helmholtz coils for controlling the magnetic microrobot [26]. The three axes Helmholtz coils composed by Cu with the resistance 2.4 Ω (X-axis), 3.3 Ω (Y-axis), 4.5 Ω (Z-axis). The radius of the Helmholtz is 142mm with 125 turns, 175 mm with 150 turns and 200mm with 180turns, respectively. Based on the Biot-Savart law, the magnetic flux density at any point on the axis of the Helmholtz coils, as shown in Fig.3, is calculated by equations (1).

$$B_x = \frac{i\mu_0 n r^2}{2}\left[\frac{1}{\left\{r^2+\left(\frac{d}{2}-x\right)^2\right\}^{\frac{3}{2}}}+\frac{1}{\left\{r^2+\left(\frac{d}{2}+x\right)^2\right\}^{\frac{3}{2}}}\right] \quad (1)$$

where, B is the magnetic flux density, $\mu_0$ is the permeability of vacuum. x is the arbitrary position from the center position of the pair coils.

While the magnetically actuated microrbot move inside fluid, the rotational magnetic field provide a magnetic torque. The microrobot can rotate and obtain a propulsive force duo to the reverse propulsion force. The magnet torque is defined by equation (2):

$$T = \mathrm{VM} \times B \quad (2)$$

where, B is the magnetic flux density V is the volume of the magnet, M is the magnetization of the magnet.

In order to realize the flexible motion, we analyzed the performance of the magnet. In our research, we use an O-ring magnet as an actuator for the microrobot, as shown in Fig.4. Fig. 5 is a sectional view of O-ring magnet. The magnetic field of the magnet is defined by equations (3)-(8). Analytical results of the magnetic flux density are shown in Fig. 6 and Fig.7. Compared with our research, the O-ring magnet is higher magnetic flux density than one magnet as actuator.

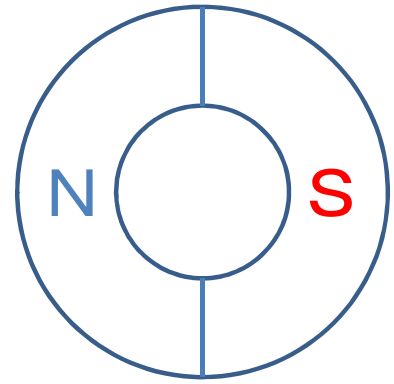



Fig.4 O-ring magnet as an actuator for the magnetic microrobot

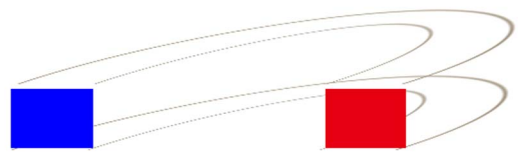


Fig. 5 sectional view of O-ring magnet

$$\oint_L \mathbf{B}\cdot d\mathbf{l} = \mu_0 \sum I \quad (3)$$

$$B_o = \frac{\mu_0 I}{2R} \quad (4)$$

$$B_R = \frac{\mu_0 IS}{2\pi\left(R^2+x^2\right)^{3/2}} \quad (5)$$

$$d\mathbf{B} = \frac{I d\mathbf{l}\times\mathbf{r}_0}{4\pi r^2} \quad (6)$$

Where, $B_o$ is the magnetic flux density of the O-ring magnet center. $B_R$ is the magnetic flus density of radius direction of the O-ring magnet.

$$\begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}^{-1} \begin{bmatrix} H_X \\ H_Y \\ H_Z \end{bmatrix} \quad (7)$$

Here,

$$\begin{cases} a_{11} = \cos\alpha\cos\beta \\ a_{12} = -\sin\alpha\cos\gamma + \cos\alpha\sin\beta\sin\gamma \\ a_{13} = \sin\alpha\sin\gamma + \cos\alpha\sin\beta\cos\gamma \\ a_{21} = \sin\alpha\cos\beta \\ a_{22} = \cos\alpha\cos\gamma + \sin\alpha\sin\beta\sin\gamma \\ a_{23} = -\cos\alpha\sin\gamma + \sin\alpha\sin\beta\cos\gamma \\ a_{31} = -\sin\beta \\ a_{32} = \cos\beta\sin\gamma \\ a_{33} = \cos\beta\cos\gamma \end{cases} \quad (8)$$

where X,Y,Z is the position of the measurement point.

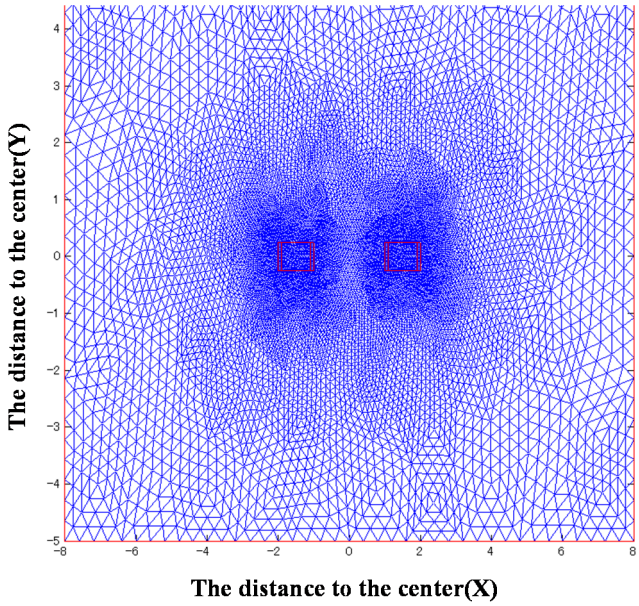



Fig. 6 Conceptual design of the rotational three axis Helmholtz coils for the magnetically actuated microrobot

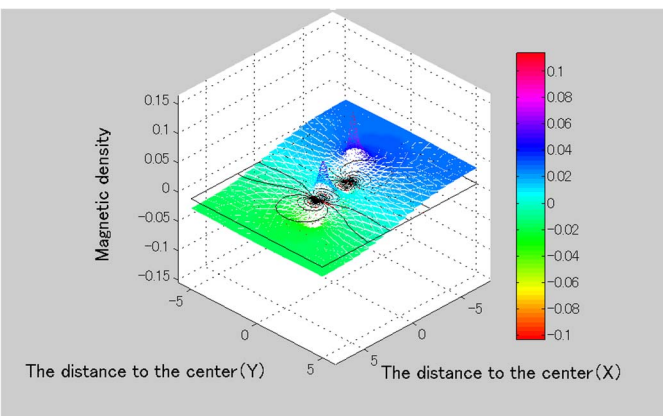
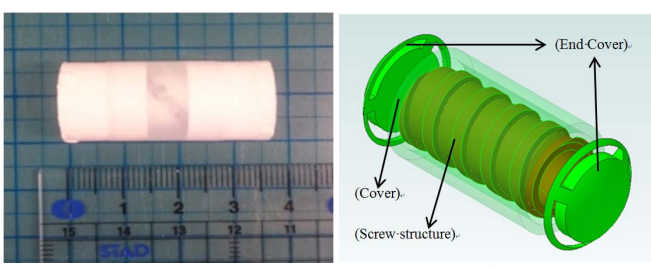



Fig. 7 Conceptual design of the rotational three axis Helmholtz coils for the magnetically actuated microrobot




(a) (b)

Fig.8 Structure of the microrobot with screw jet motion (a) Prototype of the microrobot (b) conceptual design of the microrobot

## III EXPERIMENTAL RESULTS

### A. Magnetically actuated hybrid microrobot

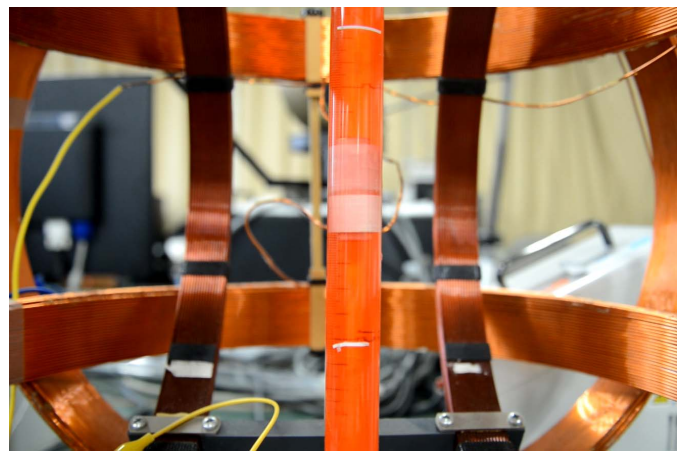
According to working principle of the magnetically actuated microrobot, many kinds of microrobots have been proposed. Various type magnets as an actuator are fitted inside microrobot, such as, cylinder, sheer and cube, and O-ring [27, 28]. They have flexible motion, simple structure, and good stability, and so on. Based on the research results, we proposed a magnetically actuated microrobot using the O-ring magnet as an actuator. The microrobot realizes the basic movement with screw jet motion, as shown in Fig.8.

### B. Experimental results

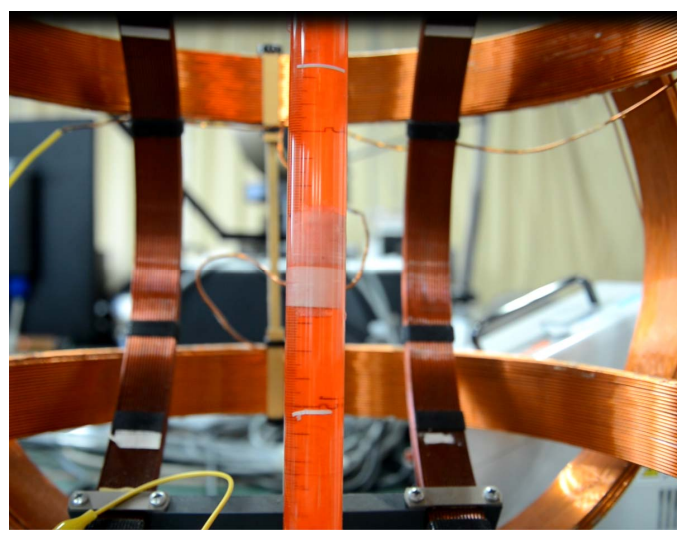
The electromagnetic actuation system is used to control the microrobot in the vertical plane, as shown in Fig.9. We adjusted the magnetic changing frequency to generate the propulsive force, and the microrobot can stop at a point in the pipe. We can calculate the force by equation (9). The experimental result is shown in Fig.10. At last, we compared the performance evaluation of the microrobot with our proposed microrobot, as shown in Table 1.

$$F_P - F_D \pm F_B \sin\theta \mp G \sin\theta + m\frac{dv}{dt} = 0 \qquad (9)$$

where, $F_P$ is the propulsive force, $F_D$ is hydraulic resistance.



(a) Upward motion



(b) Downward motion

Fig. 9 Experimental results in vertical plane

Table 1 Specification of magnetic wireless microrobot

| Microrobot | Paddling microrobot | Screw jet microrobot | Hybrid Microrbot | Screw jet motion |
|---|---|---|---|---|
| Moving mechanism | Paddling | Screw jet | Spiral & Fin | Screw jet |
| Size[mm] | Φ20×55 | Φ14×35 | φ14×77 | φ14×35 |
| Weight[g] | 4.01 | 6.10 | 3.56 | 4.28 |
| Magnet type | Cylinder | Cylinder | Sheet & Cube | O-Ring |
| Magnet Number | 3 | 4 | 1+1 | 1 |

## IV CONCLUSIONS

We proposed a magnetically actuated microrobot for biomedical application. The magnetically actuated microrobot is controlled by an electromagnetic actuation system, which generated a rotational magnetic field. In order to obtain the optimal performance of the microrobot in pipe, the performance of O-ring magnet as an actuator of the microrobot is analysed by finite element method. And we obtain the relationship between magnetic flux density and external magnetic field. At last, we evaluated the performance of the microrobot in vertical plane using our proposed electromagnetic actuation system. The microrobot with screw jet motion realized the upward motion and downward motion by adjusting the magnetic changing frequency.

## ACKNOWLEDGMENT

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