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Design and Performance Evaluation of a Novel Mechanism with Screw Jet Motion for a Hybrid Microrobot Driven by Rotational Magnetic Field

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***Abstract* – Wireless microrobots are endowed with promising future for medical tasks. In this paper, a novel mechanism with screw jet motion for a hybrid microrobot. The microrobot has a compact structure. It consists of an outer shell, a screw structure and an o-ring magnet as an actuator, which is fitted inside the microrobot. It is driven by a rotational magnetic field which is generated by three-axis Helmholtz coils. While the microrobot is in the magnetic field, the actuator is conversion of synchronous rotation with a rotating field using a "screw jet motion" to pull fluid through the centre of the microrobot. The experimental results indicated the microrobot can realize the flexible motion with good performance.**

Index Terms –Screw jet motion; Hybrid microrobot; Rotational magnetic field; three-axis Helmholtz coils

I. Introduction

Microrobot as a kind of diagnostic tool has been widely apply to biomedical application [1]-[10]. One of that is endoscopy which is used for diagnosing the human body in medical procedure. It has an important play on the biomedical applications. The traditional cabled endoscope has been applied for many years [11]-[15]. It is usually used to examine the upper part of the GI tract. But it can not arrive some narrow area inside GI tract, such as, small intestine. Compared with the traditional cabled endoscope, the wireless endoscope can solve this problem [16-19]. One kind of the wireless endoscopes obtain the motion by peristalsis. In other words, we do not control the position and orientation in the target area [14]. To achieve the flexible motion, many kinds of wireless microrobot have been proposed and developed [20-26].

Up to now, there are different kinds of wireless microrobots driven by magnetic field. The different types of magnets or electromagnetic coils as magnetic actuator are fitted inside the wireless microrobot, such as, tube-shape permanent magnet, o-ring type magnet, electromagnetic magnet [27-29]. Meanwhile, for manipulating these magnetic microrobots, various control systems have been proposed. For example, Guo and Qan developed a control system which mainly composed of the solenoid coils and the MTx sensor, to operate a fish-like microrobot. The microrobot can realized the fin motion at the natural frequency. And also, it can stop at a point inside the interesting region of system. But the movement path is limited by the shape of solenoid coils [31]. Moreover, some biomimetic microrobots have been developed. Tao et al. proposed a microrobot which is made of a kind of intelligent magnetic material [17]. Hagiwara et al. developed a high speed magnetic microrobot which is actuated in microfluidic chip [33]

Recently, several magnetic microrobots have been proposed by our groups, as shown in Fig 1. These kinds of microrobot have the basic motion, such as forward-backward motion, upward-downward motion and turning. Fig. 1 (a) shows the fish-like microrobot inspired by the movement of the fish. A MTX sensor is used to control it in natural frequency. Fig 1 (b), (c) and (d) shows the different kind of screw type microrobot, which is inspired by a drill. But these kinds of magnetic microrobot have some limitations, such as, unstable, lager size, in medical applications or industry applications. In this paper, we proposed a novel mechanism with screw jet motion for solving these problems.

This paper is organized as follows. Firstly, we introduce the conceptual design of the magnetically actuated hybrid microrobot. Secondly, the motion mechanism of the microrobot with screw jet motion is introduced. And then, the performance of the mechanism is evaluated by the experiments at last is the conclusions of this paper.

II. Proposed Magnetically Actuated Hybrid Microrobot

A. *Magnetically actuated hybrid microrobot*

Various magnetic microrobots have developed. And they can realize some basic motion, as shown in Fig. 1. According

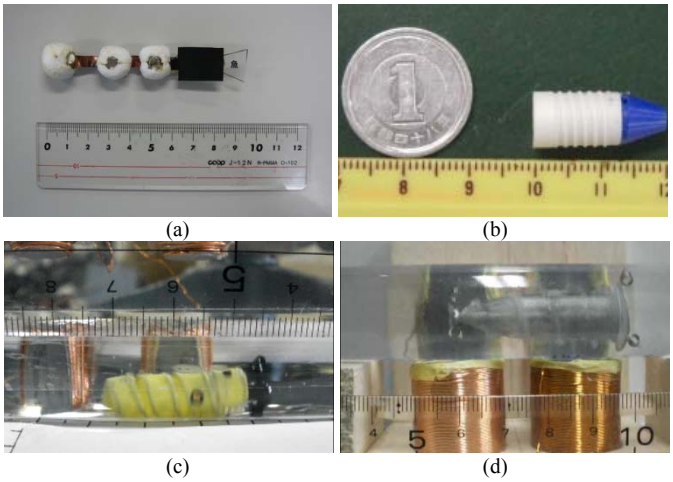


Fig. 1 Magnetic wireless microrobot. (a) shows the fish-like microrobot inspired by the movement of the fish. (b), (c) and (d) shows the different kind of screw type microrobot, which is inspired by a drill.

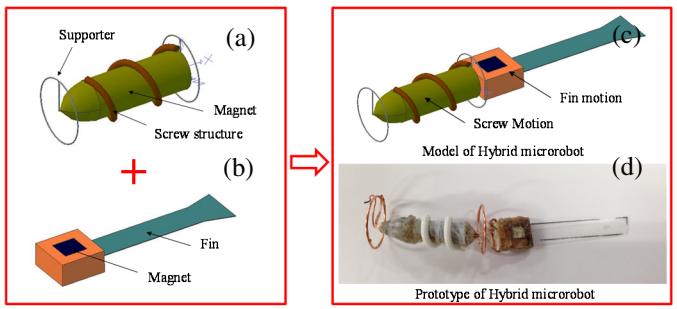
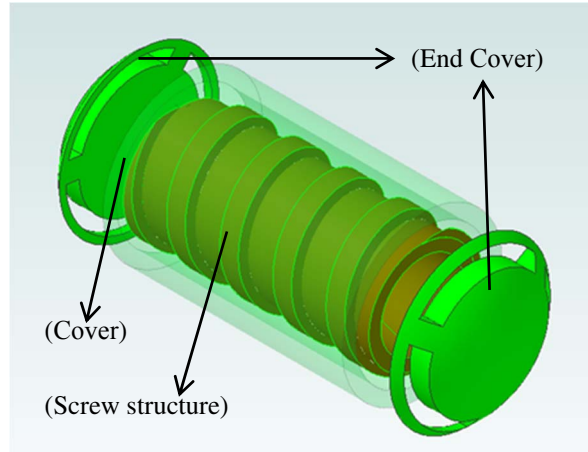


Fig. 2 Proposed Hybrid microrobot (a) spiral motion (b) Fin motion (c) model of hybrid microrobot (d) prototype of the hybrid microrobot

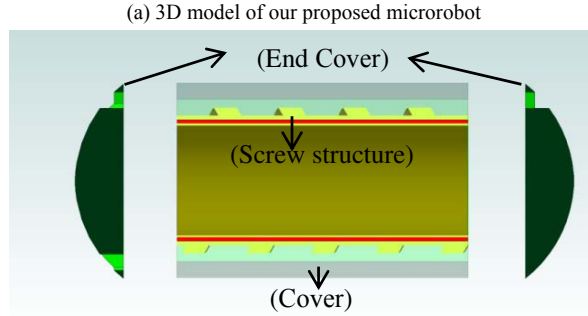
Table I
Specifications of the microrobot

Length of microrobot	35 mm
Radial of microrobot	16 mm
Weight of microrobot	4.248 g
Magnetization on direction	Radial
Radial of magnet	5 mm
Weight	1.036g
Material of body	Polythene Plastic
Material of screw structure	Polythene Plastic

to these previous researches, we proposed a magnetically actuated hybrid microrobot (MAHM) [3] [30] [31]. Magnetically actuated hybrid microrobot composed of two parts, fin and body. The body with a screw motion is used to realize the statable motion in pipe and the fin with the fin motion which likes a fish is used to realize the movement in the different environment. A magnetically actuated hybrid microrobot is proposed, as shown in Fig. 2. In order to improve the performance of this kind of magnetically actuated hybrid microrobot, we proposed a screw jet motion which is used for the body of the microrobot. And this kind of



(a) 3D model of our proposed microrobot



(b)

Fig. 3 Structure of the microrobot with screw jet motion

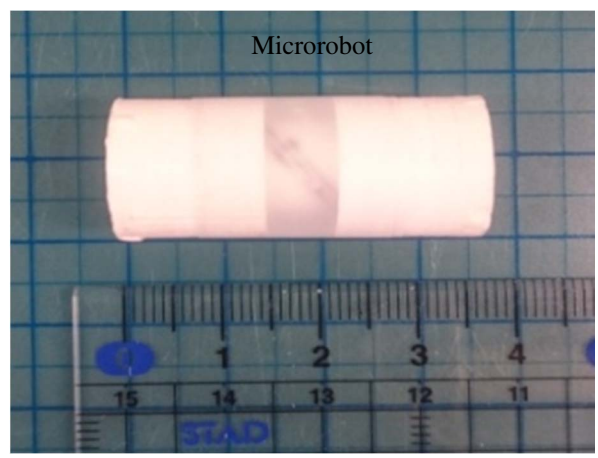
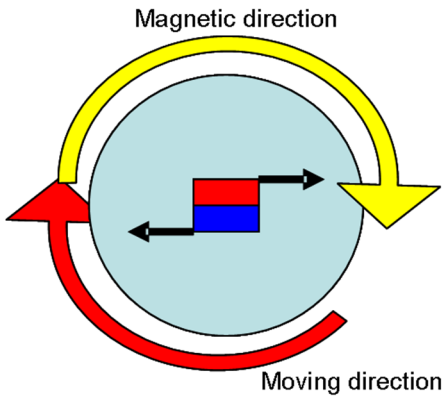


Fig. 4 Prototype of the microrobot with screw jet motion

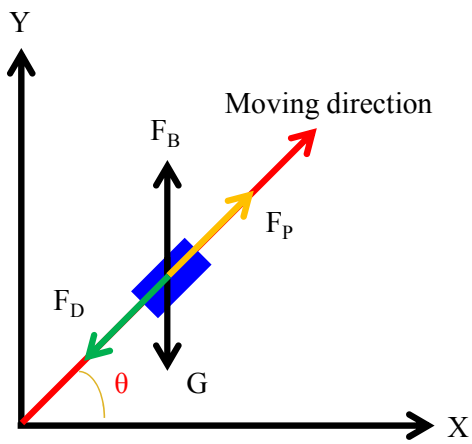
magnetically actuated magnetic microrobot just used one magnetic actuator (O-ring magnet) to realize two motions. In other words, it has a complex structure and light weight and enough space for loading the devices to achieve some functions, diagnosis, drug delivery, and so on [32]. The design of the body with screw jet motion is illuminated in Fig. 3.

B. Manufacture of microrobot with screw jet motion

The microrobot with screw jet motion is manufactured, as shown in Fig. 4. A magnetic actuator is fitted inside the screw structure by a strong adhesive. The cover of the microrobot is made of the materials-PLA by 3D printer. Specification of the microrobot is shown in the Table I.



(a) Screw jet motion of the microrobot



(b) Force acting on the microrobot

Fig. 5 Dynamic model of the microrobot

III. Motion Mechanism of the Microrobot with Screw Jet Motion

A. Magnetic force and magnetic torque

When the microrobot which has a magnet as an actuator is inside an external magnetic field, the propulsive force and torque are provided by the external magnetic field. The microrobot can rotate due to the magnetic torque T. The magnetic force F and magnetic torque T acting on the magnet inside the external magnetic field generated by the 3 axes Helmholtz coils is given by the equations (1) and (2):

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

where, B is magnetic flux density, M is the magnetization of the magnet and V is the volume of the magnet [3].

B. Force model of the microrobot

A dynamic model, as shown in Fig. 5, is built to analyse the spiral jet motion of the microrobot in fluid [32]. While the microrobot moves in the fluid, the distribution of force on the microrobot is simplified including propulsive force, hydraulic resistance, buoyancy and gravity force, as shown in Fig. 5 (b). According the Newton second law, the equation of the motion of the microrobot in indicated in equation (2):

$$F_P - F_D \pm F_B \sin\theta \mp G \sin\theta + m\frac{dv}{dt} = 0 \tag{2}$$

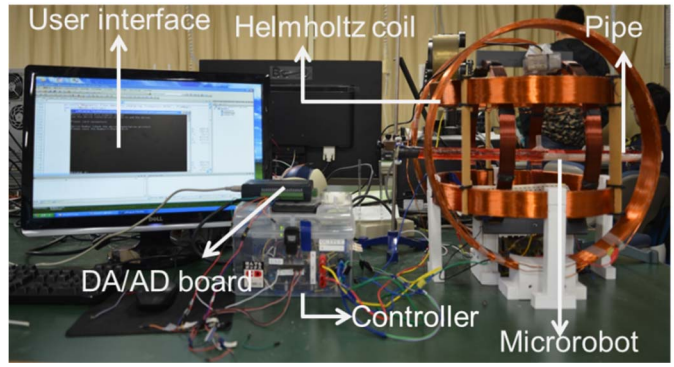


Fig. 6 EMA system.

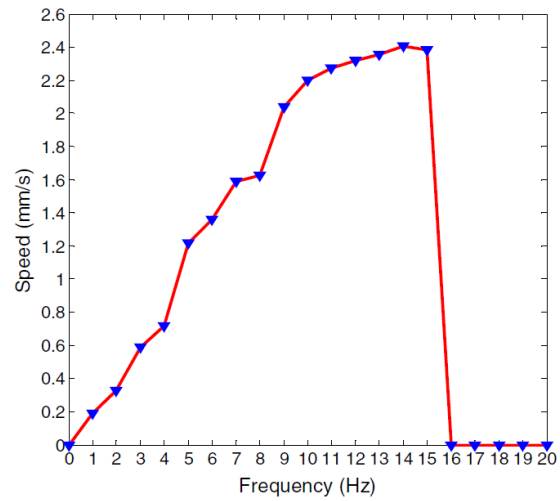


Fig. 7 relationship between the frequency and speed

F_B is buoyancy, resistance, G is gravity force, m is the mass of microrobot, v is speed of the microrobot.

The hydraulic resistance is calculated by equation (3)

$$F_D = C_D A \frac{\rho v^2}{2} \tag{3}$$

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

IV. Experiments and Results

In order to evaluate the performance of the screw jet motion, we used the EMA system (Electromagnetic Actuation System), as shown in Fig.6, to verify the characteristic of the microrobot in pipe.

A. Performance evaluation of the microrobot

The relationship between the magnetic flux density changing frequency and the speed of the microrobot is shown in Fig. 7. During the experiments, we adjusted the magnetic flux density changing frequency via the user interface from 0 to 20 Hz. We measured the speed of the microrobot with each step 1 Hz. The experimental results indicated the relationship between the magnetic flux density changing frequencies is linear before 15 Hz. After the 15 Hz the microrobot did not move in the pipe because the microrobot can no longer rotate continuously in synchronous with the rotational magnetic fields above 15 Hz [3].

(a) t=0s (b) t=5s (c) t=10s

(d) t=15s (e) t=20s (f) t=25s

(g) t=30s (h) t=35s (i) t=39s

Fig. 8 Forward-Stop-backward motion. (a) (b) (c) (d) shows the forward motion of the microrobot. (e) and (f) shows the microrobot stop at a point. (g) (h) and (i) shows the backward motion of the microrobot

B. Forward-stop-backward motion

According the experimental results, we designed a composite experiment, forward-stop-back motion in the pipe, as shown in Fig. 8. The experiment results indicated the microrobot has a flexible motion in the pipe.

V. Conclusions

In this paper, we proposed a novel mechanism with screw jet motion for the magnetically actuated hybrid microrobot. The microrobot with screw jet motion is driven by the rotational magnetic field, which is generated by our proposed electromagnetic actuation system. The screw structure is used to pull fluid through the centre of the microrobot. The experimental results indicated that it realized the flexible motion in the pipe, forward-stop-motion. The screw jet motion has a potential to be used our proposed magnetically actuated hybrid microrobot in the future. And the performance of the microrobot with different parameters should be evaluated to improve the performance and obtain the optimal speed.

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