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Study on no-power-supply steerage for endoscope capsule – Combination of magnetic force and ultrasonic beacon –

内視鏡カプセル等の無給電操舵の基礎研究 – 磁場操舵と超音波ビーコン併用の可能性 –

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1. Introduction

Endoscopy has become a popular medical diagnosis method nowadays. Recently endoscope capsules have been developed and provided by several companies, i.e. Given Image Ltd. and Olympus Medical Systems Ltd. Today's capsules have functions of taking photographs of internal organ walls, especially stomach and intestine walls, and store the data into several G-Byte memory included in the capsules. However they cannot be controlled to turn and move by external key-board or joystick commands.

Since endoscope capsules are brand-new products, there are a lot of demands for improving their performances and adding new functions to them. Real-time observation, controllability from external commands, farther miniaturization and battery-less, addition of manipulation functions, etc. are the typical demands necessary to be investigated. The first one will be achieved by BAN (Body Area Network) technology and extremely-low-power consumption circuit technique in near future. In this paper, we focus on the second item, that is external control of endoscope capsules.

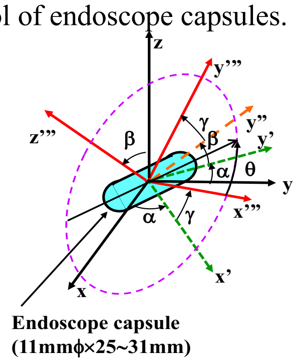


Fig. 1 Turn on any plane and move in any direction of endoscope capsule.

2. Requirements of no-power-supply steerage for endoscope capsule

The endoscope capsule has no motor to move independently, so no-power-supply steerage is crucial for its turning and movement. In general, it has a camera at one end of capsular body. As shown in Fig. 1, the size is a diameter of about 11 mm and a length of 25 to 31 mm. It must turn to right and left on a given plane and move forward. We investigate a couple of method. Recently-proposed wireless power transfer using LC resonant phenomenon is one certain technique, but a motor is necessary in this case. In order to achieve both turning and movement, we decide to study a method using magnetic force as no-power-supply steerage and ultrasonic-beacon method to indicate direction of the capsule.

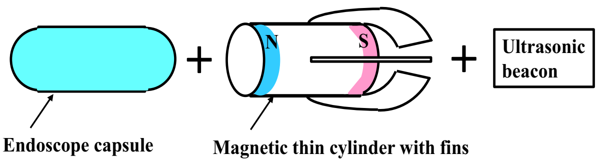


Fig. 2 Proposed structure to achieve no-power-supply steerage.

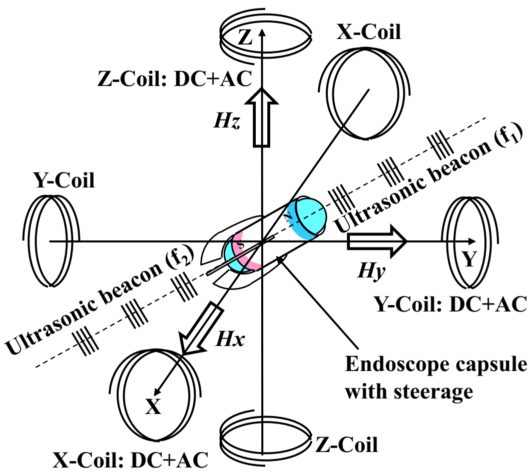
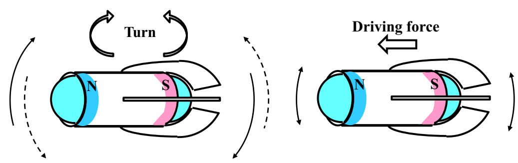


Fig. 3 Total system with no-power-supply and ultrasonic beacon.



(a) Turning by DC (b) Movement by AC
Fig. 4 External control by superposition of DC and AC voltages.

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3. Proposed no-power-supply steerage with directivity sensing

Schematic illustration of the structure to achieve no-power-supply steerage is shown in Fig. 2. Using commercial endoscope capsules, we add functions of no-power-supply steerage and ultrasonic beacon to sense the direction of the capsule. The former can be achieved by a thin cylinder type magnet with fins, while the latter by conventional ultrasonic technique. As shown in Fig. 3, magnetic fields, *Hx*, *Hy* and *Hz*, are generated by external X-, Y- and Z-coils. If controlling the capsule to turn and move on an arbitrary plane given by Fig. 1, magnetic fields produced by coils are given as follows:

$$Hx = H\sqrt{\cos^2\alpha + \sin^2\alpha\cos^2\beta}\ \cos(\theta + \gamma + \varphi_x) \quad (1a)$$

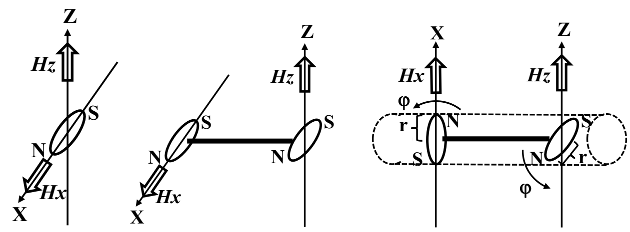
$$\varphi_x = \arctan(\tan\alpha\cos\beta) \quad (1b)$$

$$Hy = H\sqrt{\cos^2\alpha\cos^2\beta + \sin^2\alpha}\ \sin(\theta + \gamma + \varphi_y) \quad (2a)$$

$$\varphi_y = \arctan\left(\frac{\tan\alpha}{\cos\beta}\right) \quad (2b)$$

$$Hz = H\sin(\theta + \gamma)\sin\beta \quad (3)$$

Turning to right and left can be achieved by the above magnetic fields, which corresponds to applying DC voltages to coils as shown in Fig. 4(a). In order to move the capsule, we induce small vibrations of the capsule by superposition of AC voltages to above DC voltages. Due to fins attached to the magnetic cylinder, driving force is produce by vibrations as shown in Fig. 4(b).



(a) X-Z plane
(b) Separation of X and Z axes
(c) Rod with two magnets
Fig. 5 Two-dimensional model to check proposal.

4. Generation of two-dimensional rotation

In order to check the basic concept of our proposal, we investigate two-dimensional rotation assuming a simple rod model.

4.1 Theoretical investigation

We simplify Fig. 1's model to X-Z two-dimensional case as shown in Fig. 5(a). Magnetic poles are attracted or repelled by *Hx* and *Hz*. In order to treat mathematically easily, we separate X and Z axes as shown in Fig. 5(b). The capsule is also divided into two parts, but they are connected by a weightless bar. To verify experimentally later, X axis is rotated by -90° to be paralleled to Z axis as shown in Fig. 5(c). Moreover, an imaginary cylinder which externally touches capsules is considered.

We assume that sinusoidal voltages with angular frequency of ω are applied to coils, so in Eqs. (1) to (3) $\alpha = \beta = \gamma = 0$ and $\theta = \omega t$. In Fig. 5(c), torques by *Hx* and *Hz* are given below,

$$\tau_x \sim 2\,r\sin(\varphi)\cos(\omega t) \quad (4a)$$

$$\tau_y \sim 2\,r\cos(\varphi)\sin(\omega t) \quad (4b)$$

So, the total torque to a cylinder is $\tau = \tau_x + \tau_y \sim 2\,r\sin(\varphi + \omega t)$. The cylinder rotates to make τ become zero, which leads to $\varphi = -\omega t$, that is counter clockwise rotation. If $Hx \sim \sin(\omega t)$ and $Hz \sim \cos(\omega t)$, then $\varphi = \omega t$, so clockwise rotation can be obtained.

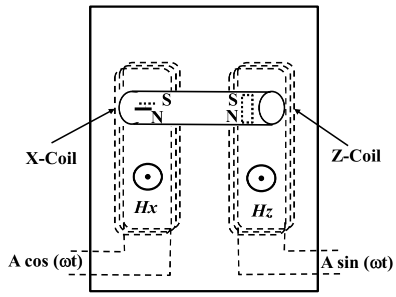


Fig. 6 Experimental set-up for Fig. 5(c)'s two-dimensional model.

4.2 Verification by fundamental experiments

In order to check our proposal and theoretical investigation in 4.1, we do fundamental experiments. Experimental set-up shown in Fig. 6 is exact embodiment of Fig. 5(c)'s imagery model for the theoretical investigation. We apply A cos (ωt) to X-coil and A sin (ωt) to Z-coil, and vice versa to observe rotation of a cylinder. The results will be presented in the symposium.

5. Conclusion

We proposed new no-power-supply steerage for endoscope capsules using thin cylinder type magnet with fins. Fundamental experiment using a prototype will be conducted.

References

1. Home page of Given Image Ltd., http://www.givenimaging.com/.