B0-field-driven capsule endoscope with swimming tails for propulsion : design study

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INTRODUCTION

Capsule endoscopy has proven to be a useful tool for gastrointestinal diagnosis (1). Part of the colon is not reachable by traditional endosocpy or by colonoscopy; the capsule endoscopy was superior to push enteroscopy in the diagnosis of recurrent bleeding in patients who had a negative gastroscopy and colonoscopy near these lesions (2). The pill-shaped endoscope that has a small camera and transmits by a radio frequency communication unit images of the small intestines to an exterior receiver. The shortcomings of today's capsule endoscope depends on natural peristaltic motion created in the intestines and no active control to go back the disease site is possible nor precise localization of the site in diagnostic cross sectional images have not yet reported. In this study, we propose the method to use of MRI's constant magnetic field to propel a capsule and navigate the endoscope by real-time MR imaging. Specifically, the purpose of this study is to design the capsule endoscope driven by the static field of MRI and assess the feasibility of fabrication. We present our preliminary design of the endoscope and simulate the propulsive force and power source required to drive the capsule inside stomach.

METHODS

Several studies have used external magnetic fields to position micro-robot in fluid and the used MRI magnetic fields to maneuver objects in the body. In these studies the manipulated object is a permanent magnet and the external magnetic field alternates (3) and/or changes its direction (4) in order to create the forces to propel the micro-robot and moments to rotate it. Such methods can't be used inside the MRI, because the ferromagnetic material creates a large artifact and the external alternating fields disturb the functioning of the MRI. Another disadvantage of the permanent magnet manipulation is that propelling force cannot be created in the direction of the polarization of the magnet.

We designed a magnetic driven miniature robot using the static magnetic field of the MRI (B0) to create propulsive force in 3 degrees of freedom (including the direction magnetic field B0). The magnetic propulsion is based on the Lorenz force which is the force created on a wire conducting electric current placed in an orthogonal constant magnetic field normal to the plane created by the wire and the magnetic fields directions (Figure 1). The batteries of the smart pill will provide current to the driving circuitry of a set of three rectangular coils placed on an elastic tail. The coils will invoke a traveling bending wave in the cantilever which is able to create effective propulsion in viscous flow environments. The traveling wave in the swimming tail is created by entering different amplitudes and phases in each magnetic coil similarly to the on e created by piezoelectric actuators in (5-7). Propulsion in three degrees of freedom is achieved by placing swimming tails in three orthogonal directions (Figure 2). None of the components of the swimming smart pill in the MRI has to be made of ferromagnetic metals thus the interference to the MRI's function will be minimal.

RESULTS

Communication unit and power source for the smart pill size is 11 [mm] in diameter and 27 [mm] in length; the weight of this smart pill is 3.7 [gr] using commercially available components. Overall assembly of the robot is shown in Figure 2. The camera unit is 3.5 [mm] diameter and the length is 3 [mm]. Assuming the propulsive force created in this method will be similar as the propulsive force in (5-7) the size of the swimming tails with the coils will be 10X1.5X0.2 [mm]. We assume that the current in the coils is 1 [mA] and the frequency that needed for such a tail is 3.5 [kHz]. Assuming we use a standard hearing aid batteries (Renata ZA 10, diameter 5.8 [mm], height 2.1 [mm] nominal voltage of 1.4 [V] and capacity of 35 [mAh]), the power of such the swimming tail consume is 1.4 [mW]. One such battery can supply energy for 3.5 [hr] for the actuators alone. The Lorenz force created in each coil orthogonal to the B0 magnetic field is given by $F = B[Te] \times i[A]$. Assuming the static magnetic field in the MRI is 1 [T] the force created by one wire is on the tail is 1 [mN] which is sufficient to drive the capsule in the gastric cavity. The numeric simulation showed that a such a swimming mechanism can provide one swimming tail of 10X1X0.02[mm] propulsive velocity of 1 [cm/s]. Taking into account the added drag by the head section and the additional tails we think the MRI swimming micro-robot can achieve such a propulsive velocity too.

DISCUSSION and CONCLUSION

We present a novel propulsion method taking advantage of the static field of the MRI that can be downscaled by novel MEMS technologies. This hybrid endoscopic/MRI technology will enable new medical abilities that cannot be imagined at this point of time. Further work will be coducted to fabricate this capsule endoscope in real world settings. (This work was supported by 1U41RR019703)

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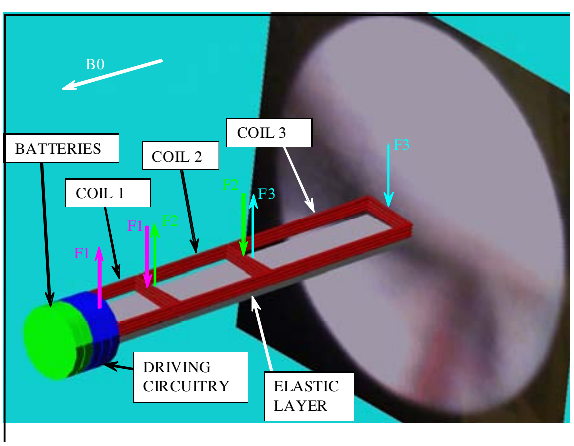

Figure 1: Illustration of the swimming tail. The Lorenz forces created by each coil (coil 1 red, coil 2 green, coil 3 cyan) creates a traveling wave along the elastic bending layer. In the background appears an endoscopic image of the spinal Subarachnoid space

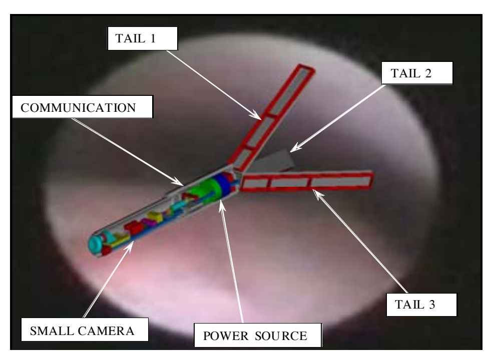

Figure 2: Illustration of the swimming tail with a smart pill as payload. The tree tails enable 3 DOF propulsion. The micro robot contains the following components: 3 swimming tails, Battery power source, communication unit and a small camera. In the background appears an endoscopic image of the spinal Subarachnoid space