2014 5th IEEE RAS & EMBS International Conference on
Biomedical Robotics and Biomechatronics (BioRob)
August 12-15, 2014. São Paulo, Brazil

Conceptual Design of Micro-Hydraulics System for Active and Biopsy Capsule Endoscope Robot

Hernando Leon-Rodriguez, Cheong Lee, Le Viet Ha, Seong Young Ko, Jong-Oh Park* and Sukho Park*, *Member, IEEE*

Abstract— **Capsule endoscope is commercial design product used as a medical device for endoscopy test in the small intestine preferably. This paper presented a novel conceptual design and power mechanism in order to perform a capsule endoscope robot with micro-hydraulic biopsy tools system. The capsule endoscope presented can moves as active device, powered externally by an electro-magnetic actuation system (EMA). The EMA system can be frequency adjust to activate the micro-hydraulic pump as the main power generator to perform the micro-actuator and/or micro-biopsy tool. The conceptual design is focused in two capsule containers; these are proposed to be able to obtain additional space for the biopsy tools. Preliminary test of the micro-pump power by EMA system are presented for future application of capsule endoscope with active motion maneuvers and micro-biopsy tools operation in real-time.**

I. Introduction

Recently, gastrointestinal (GI) diseases are evaluated by perform a very unpleased devices introduced by the natural holes of the digestive system. These typical procedures are been perform by medical doctor on upper or lower visual endoscopy examination. The endoscope is a tiny high definition camera on the end of a long flexible tube with several kind of cutting devices or biopsy tools. A specialist in diseases of the digestive system (gastroenterologist) uses endoscopy to diagnose and, sometimes, treat conditions that affect the esophagus, stomach and beginning of the small intestine (duodenum); but also, they perform a lower endoscopy (colonoscopy) which visualised the large intestine [1].

Since 2001 a novel and relatively pleasure endoscope device had emerged in order to exanimate the digestive tract with low invasion. This device is called wireless capsule endoscope, which has the capability to move into the digestion system by the peristaltic motions and simultaneously takes several numbers of pictures and send them out to one portable receiver device.

Nowadays the capsule endoscope is required not just to be able to take pictures and send them out from the body; its new requirements are localization, position control, carry and perform biopsy procedures and hopefully drug delivery. To achieve these new parameters researches are focus in develop different alternatives of active navigation of capsule endoscope equipped with biopsy tool for wireless activation.

One alternative is an elastic element called magneto mechanical that can be loaded remotely by varying the magnetic field surrounding it. It is able to store and release mechanical spring energy, triggered externally. It can store multiple samples large that 1 mm^3 due of reservoir underneath its cylindrical rotating blade [2]. The mechanism is based in the rotation of two axial permanent magnets, where one of them is fixed and the other produce the turn by high external magnetic field.

Other biopsy micro actuator idea for capsule endoscope is composed by a cylindrical shape of 10 mm diameter and 18 mm length. Its actuator is based in a spring locked by polymer string, when the sampling target is decide the actuations is perform by heating a wire that make the polymer to meld. As a result of the trigger a micro-spike in the actuator moves forward and backward using a slider-crank mechanism [3].

One more mechanically challenging micro-motor actuator was proposed as alternatives of capsule endoscope with a biopsy tool. It has the capability to stretch into to sampling point, bite and cutting off and withdrawing the sample into capsule body by doing this process automatically [4]. This system is relatively large considering the size regulations approved by food and drugs administration in 2001, but apparently is can be useful in the large intestine.

Considering the difficult conditions and specifications listed forward on this paper, a novel conceptual idea of a micro-hydraulics system is presented as an alternative of active capsule endoscope with biopsy tool. The hydraulics systems can be power and control by an electromagnetic actuation system (EMA) based in the combination of Helmholtz and Maxwell coils and voltage and frequency adjust in a micro-scale [5].

This paper describes a novel alternative of powered biopsy tools for the active capsule endoscope by controlled EMA

* This research was supported by the Industrial Strategic Technology Development Program (10030037, CTO Therapeutic System) funded by the Ministry of Trade, Industry and Energy (MOTIE, Korea), by the Leading Foreign Research Institute Recruitment Program (No. 2012-026740) through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (MEST, Korea) and by the Nueva Granada Military University of Colombia.

Hernando Leon-Rodriguez, Cheong Lee, Le Viet Ha, and Seong Young Ko, are with the School of Mechanical Engineering, Chonnam National University, Gwangju, 500-757, Korea (e-mail: leonhernando@gmail.com, vdkqydh@naver.com, leviethavn@ gmail.com, and sko@jnu.ac.kr,)

Jong-Oh Park and Sukho Park are with School of Mechanical Engineering, Chonnam National University, Gwangju 500-757, Korea (corresponding author phone: 82-62-530-1687; fax: 82-62-530-0267; e-mail: jop@jnu.ac.kr and spark@jnu.ac.kr).

system on the base of micro-hydraulic system composed of one micro-pump as a main generator.

II. Design Considerations and Specifications

Based on MEMS technology the introduction of wireless capsule endoscope was the results of advances in micro-fabrication and efficiency of electronics technology. The goal was the miniaturization of one camera and lighting system squeezed in a pill-size that can moves passively through the digestive system and enables visualization of the GI tract without discomforts. Nevertheless, new conditions had emerged for the capsule endoscope due of limitation and unfair collate of wired flexible endoscopy.

The capsule endoscope should be an external biocompatible shell, with a size of a large antibiotic pill (11 mm in diameter, 26 mm in length) approved by food and drugs administration 2001 for use in adults and in 2003 for use in children older than 10 years [6]. The capsule endoscope is composed by a wireless communication unit, vision module and a power source.

The wireless communication module or (receiver) is plugged with several electrodes-cups (array of sensors) placed on the patient abdomen, similar to long-term electrocardiogram techniques in order to collect wirelessly data from the capsule when its moves by the peristaltic motions in the digestion system. The vision module consists in one micro-camera with the highest quality images possible on this size which could around (320x 320 pixel); but, in order to optimizes images quality is necessarily an automatic brightness control of 4 to 6 white led lights to enable clearest images and also transmitted in real time from field of view.

Once the capsule is swallowed in the digestion system it moves at a rate of 1–2 cm/min and meanwhile several numbers of pictures (3 to 12 per second) are taken by approximately 8 hours of the procedure; all these pictures are sent and stored to a portable device outside the patient and downloaded by the medical doctor at the end of the process. Software is necessarily to support the doctor in identifying suspicious damage of GI track. The bowel preparation procedure is similar to the traditional flexible wired endoscopy, it requires ingestion of a strong laxative to ensure adequate bowel cleanness and facilitate progression of the capsule through the GI tract.

The new generation of the capsule endoscope requires new considerations which some of them are list as follow:

• Size: the smaller volume the larger will be the population able to swallow it is limited to 11mm diameter and 26mm in length, approved by food and drugs administration 2001 [6].

• Biopsy tools: considering the capsule as an endoscopy device several micro-biopsy tools are require to be performing in the affected area and collect the maximum size of tissue samples; at least 5 mm^3, and keeping them in the same container.

• Tissue Cutting Pressure: The biopsy mechanism must provide a sufficient force for efficient cut at slightest; this value is being tested by the reference, which is about 10N [4].

• Actuation: mechanic actuation can be apply by electrical motors but have a big disadvantage of none been micro-scalable and robustness. Other alternatives are magnetic and/or electromagnetic mechanisms which can be reducing at the micro-scale. Another option is electric-polymers which also can be decreased at micro-scalable but for now they have a low strength.

• Manipulation and/or Navigation: medical doctors require be focus in particular areas of the affected GI track, so passive peristalsis motion is needed to be change for active navigation and manipulation by a specialist, this can be given by the electro-magnetic actuation (EMA) system.

• Localization: this is obvious requirement of detection and localization of the capsule, when it has reach the small intestine or target area for biopsy sampling.

• Storage: Biopsy test consists in one to five tissue samples approximately 1 mm volume each; also, tissue samples must be kept in the same reservoir does not alter the diagnostic, to deal with, it can be stored up to 24 h on gauze soaked with liquid solution [4].

• Safety: The sampling mechanism design must be fail safe, to avoiding the risk of unlucky perforation in GI track and retention [6].

• Effective steadiness: For a successful sampling gather, the capsule must firmly adhere to the target area tissue [4].

• Energy consumption: it can produces by high rate of lithium batteries, but these are take about 50% of actual capsule space, other alternatives are under research like wireless energy transmitter by external electro-magnetic system.

III. Conceptual Design of Micro-hydraulics System for Biopsy Tools Operation

Figure 1 is showing a conceptual design and a rapid prototyping of an active-biopsy capsule endoscope robot composed by two main capsule containers (front and rear case). The aim of the design is to deploy micro-biopsy tool in a specific target area teleoperated by the endoscopist. Due of actual difficulties of narrow space in the capsule itself, the proposal is to split all components in separate cases as a modular robot, to be able to add a biopsy mechanism on the front container and keep the approved size and specifications.

The front capsule container is composed by the biopsy mechanism and cutting tool, the vision module, light module, wireless module and magnets. The clue to have the vision module in the front case is obtained the real-time images for navigation and biopsy manipulation performed by the medical doctor. The biopsy mechanism is based in micro-hydraulics devices operated externally by an EMA system. Primary experimental results of a micro-pump powered by EMA system are presented, and a first prototype is also presented. In addition, the front container will have a double clear dome to keep the electronics components protected. Foldable dome could be one alternative to keep the biopsy sample safe.

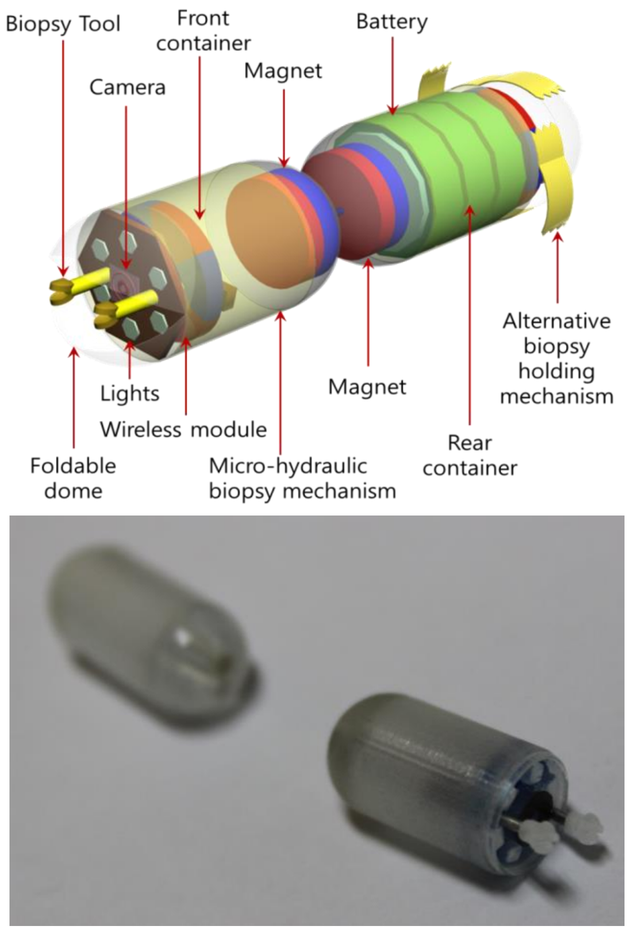
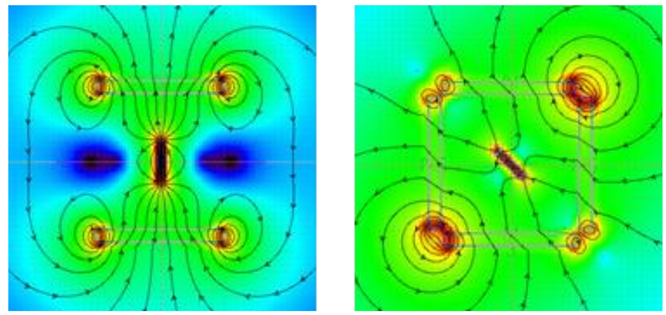


Figure 1. (Up) Conceptual design of active capsule endoscope deploying biopsy tool (Down) first prototype of the conceptual capsule design

The rear container is composed by batteries, alternative biopsy holder mechanism and a set of magnets to face and joint with the front capsule container. The front and rear capsule containers cannot operate independently, they need each other; they are electric and magnetically connected in order to provide power to the electronics modules. The rear container can be arranges to receive additional cases if more power is require. On the size of the patient, he/she just needs to take two or three capsules independently at the same time in order to proceed with the endoscopy exam; the capsules will joint automatically or can be align in the stomach by magnetics field of the EMA system.

IV. Electromagnetic Actuation (EMA) System

A pair of Helmholtz coils generates a uniform magnetic field, generally consisting of two identical circular magnetic coils, where the radius (r) of the coils is equal to the distance (d) between the coils [7]. In addition, the applied currents in these coils flow in the same direction and have the same intensity in order to produce continuous magnetization, see Figure 2a. With a second pair of Helmholtz coils placed 90 degrees the EMA system can generation a second magnetic field. If the currents of the two circular Helmholtz coils flow in the same direction and have the same intensity, the results are a 45 degree angle of magnetic field orientation in the region of interest (ROI) and a large working space (Figure 2b).



(a) (b)

Figure 2. Simulation of Helmholtz coils generated uniform magnetic field

Based on these characteristic the two pairs of Helmholtz coils can generate a uniform magnetic field in a desired direction to align a micro-magnetic device with also a desired torque (τ). To produce a torque with magnetic field by Helmholtz coil pairs and align the micro-magnet, it can be expressed as follows:

$$\tau = VM \times B \qquad (1)$$

Where: V and M denote the volume and magnetization of the micro-magnet and B means the magnetic flux [8][9].

V. Experimental Setup

An electromagnetic actuation system was used to carry-out the experimental tests. The device is composed of 3 Helmholtz coil and 2 Maxwell coil in x, y, z axis, but only x and y of Helmholtz coil were set to perform preliminary trials for powered some micro-rotors and a micro-hydraulic pump in Figure 3.

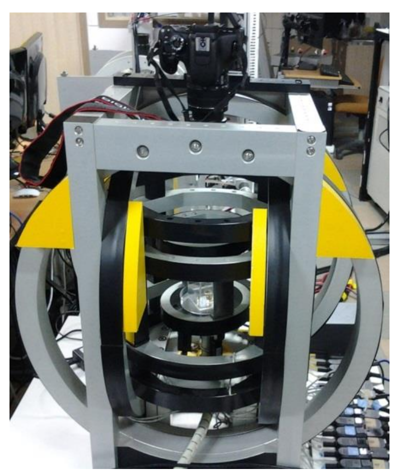


Figure 3. Electro-magnetic actuation system

The combination of the two magnetic fields in x-axis and y-axis are controlled by computer using Lab-view software via GPIB protocol. The system was power at 150 V dc with limited current of 5 Amp. The proposed micro-hydraulics pump can be powered and controlled by EMA system as shown in the Figure 4.

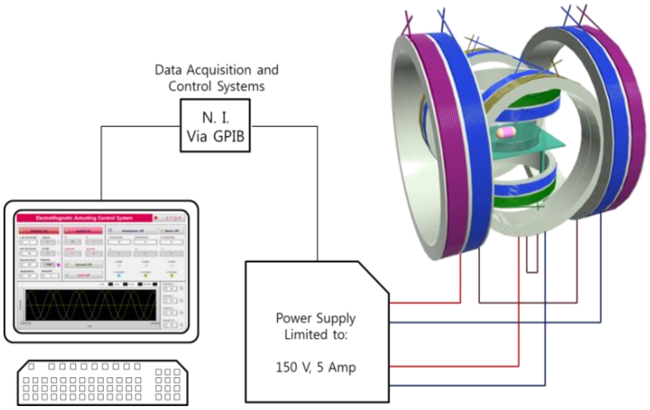
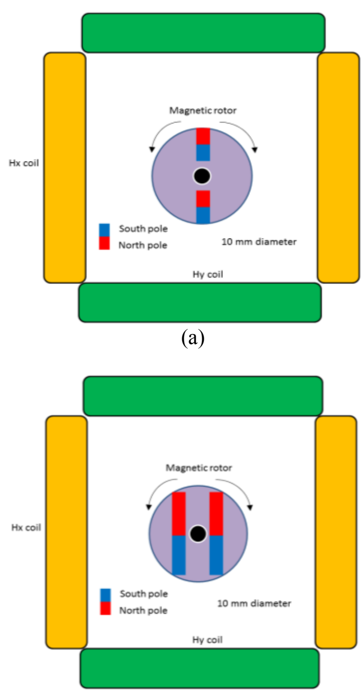


Figure 4. Schematic diagram of EMA system power micro-hydraulics pump

The two pairs of cylindrical shaped Helmholtz coils are placed in the x- (Hx), y- (Hy), these can produce any direction of magnetic field by modify the current front positive value to negative on each pair of coil. As a result the Helmholtz coils generate a rotational magnetic field using sine wave currents [8]. The rotational motion in the axial direction of the micro-hydraulic pump can be represented as follow:

$$B_{rot.} = M\,[\cos\varphi\cos\theta,\ \cos\varphi\sin\theta,\ \sin\varphi]^T \qquad (2)$$



(b)

Figure 5. Efficient arrange magnet into 2D Helmholtz EMA system rotation

The figure 5 is showing the schematic set-up of the hydraulic pump that swapped by the generation of a magnetic field between the Hx and Hy coils. The magnetic orientation of the magnetic-rotor aligns the magnetic field controlled by the operator. The angular speed (ω) is directly proportional to frequency value set in the GUI. The direction of the generated propulsion (cw, ccw) is also determined by the magnetization direction. Different type of magnets arranges can be adapted in the rotor impeller, but essentially an axial high pole neodymium magnet is the most efficient in the EMA system.

VI. Experimental Results of Preliminary Test with EMA System Powered Micro-Magnetic Pump

First, when one pair of Helmholtz coils generates a uniform magnetic field, the micro-rotor was aligned with the x-axis or y-axis direction. Second: when both Helmholtz coils generates a uniform magnetic field, the aligned direction of the micro-rotor is about 45°. Therefore, it confirmed that the magnetization direction of the micro-rotor could be regarded as simulation result given in Figure 2.

Basically, the high magnetic field induced by the EMA system force the magnetic rotor to follow the same orientation as it is given externally; so additional orientated magnets with different angles in the impeller rotor divergences with the given orientation.

The EMA system vary the given current in the coils between positive values and negative values, these variation of the two pair of coils (x-axis and y-axis) reproduce a sinusoidal response like bi-phase AC voltage skewed 90 degree. (See Figure 6) The frequencies given by EMA system can be adjusts, it becomes a proportional rpms reproduced in the impeller rotor.

A set of micro-rotors and micro-hydraulic impeller of

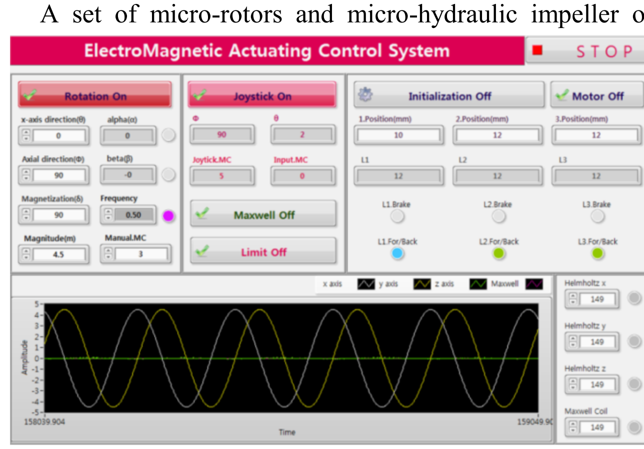


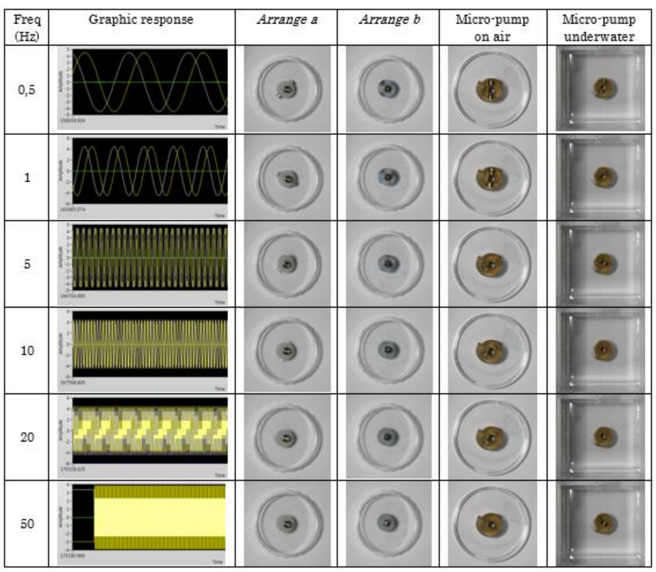
Figure 6. GUI of EMA system – Sinusoidal response of 2D Helmholtz coil, Lab-view interface

10mm diameter were tested on air and underwater in the ROI of the EMA system; the respond of all rotors were as expected. If the frequency of the given current increases the micro-rotor follows this angular speed. Different frequencies were given as a preliminary test as 0.5, 1, 5, 10, 20, and 50 Hz.

VII. CONCLUSIONS

A conceptual design of active capsule endoscopy was presented as a novel alternative of further design of commercial available; the aim of this design is to split most of main components in two capsule containers to meet the size given by the food and drugs administration 2001. The capsules required to work together as one unit devices. It can joint in the stomach of the patient due of magnetic arranges proposed. Different arranges of magnetic configuration were tested in the EMA system, but the most effective rotors are the axial magnetic arrange, as a results, the micro-rotors should be design with two pole for effective respond in the EMA system. Further research need to be done. The EMA system is a 3D arranged magnetic field, which can be controlled in several ways by combine the Helmholtz and Maxwell coil in any orientation as an external induced power supply, the micro-hydraulics pump, responds as expected in air up 50 Hz, but at the same frequency in underwater, the rotor stop rotated due of water frictions. Further research, trials and prototypes design needs to be test in order to produce the new generation of capsule endoscope performing micro-hydraulic biopsy tools. Different electronic materials for actuation can be also as alternatives of acting the micro-valves, micro-cylinder and micro-hydraulics pump controlled electro-magnetically; still long time to go, we will see in the future.

TABLE I. RESULT OF PRELIMINARY TEST OF EMA SYSTEM AND MICRO-HYDRAULICS IMPELLER



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