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Wireless capsule endoscopy Locomotion

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요 약 무선 캡슐 내시경 (WCE)은 세기 초에 개발 될 수 있는 가장 영향력 있는 바이오 의료 전자 기술 중 하나였다. 기존의 내시경 진단과 비교하여,이 응용 프로그램은 이에 훨씬 더 사용자 친화적인 방식으로 전체 위장관 (GI) 트랙을 검사하기 위한 새로운 대안을 가진 외과 의사를 제공하는 비 침습 및 저 위험이 특징이다. 그 이외에도 일반 하드웨어 업그레이드에서 WCE 연구의 국경은 기본적으로 캡슐의 소형화 및 활성화 운동에 있다. 운동은 일반적으로 자연적인 연동 운동의 함수이다 현재 상용화 WCE 제품의 본질적인 결점을 극복하기 위해, 활성 운동력 효과적으로 다른 장기에 장치를 탐색 대상으로 인간 내 치료 기능을 수행하기 위해 사용되는 전략의 시리즈로서 제안 조직과 연구의 측면에 대한 몇 가지 새로운 디자인의 리뷰는 이 문서에서 논의 될 것이다.

Abstract Wireless capsule endoscopy (WCE) was one of the most influential bio-medical electronic technologies to be developed at the beginning of the century. In comparison to traditional endoscopic diagnosis, this application is characterized as non-invasive and low-risk, thereby providing surgeons with a new alternative for inspecting the entire gastrointestinal (GI) track in a much more user friendly way. Apart from regular hardware upgrades, the frontier of WCE research basically lies in the miniaturization of the capsule and in active locomotion. In order to overcome the intrinsic drawback of current commercialized WCE products, which is that locomotion is generally a function of natural peristalsis, active locomotion is proposed as a series of strategies used to effectively navigate the device into different organs and conduct therapeutic functions within targeted human tissues. Reviews of several novel designs with respect to this aspect of research will be discussed in this article.

Key Words : Wireless capsule endoscopy, gastrointestinal, surgeon

1. Introduction

The idea of wireless capsule endoscopy (WCE) was first proposed in 2000 in Nature, which depicted a new assistant in the diagnosis of gastrointestinal (GI) tract diseases, including cancers, ulcers and bleeding [1]. This new technology can visualize the entire GI tract in a non-invasive way and thus overcomes the intrinsic drawbacks of traditional examination approaches, for example, gastroscopy and colonoscopy, which are normally torturous and incapable of detecting small intestine problems [2]. The great innovation and feasibility of WCE immediately captured huge interest amongst medical manufacturers and in 2000, Given

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Image, an Israeli company, released their first WCE product: M2A [3]. The device is 30 mm in length and has a radius of 5.5 mm; it can be easily ingested by the patient and continuously delivers pictures (more than 50000) during the following 7-hour working period. In the next decade an increasing number of institutions began to investigate and promote their own capsule endoscope, including: Olympus Inc., Japan and Jinshan Science and Technology, China. Their products also have positive feedback from clinical trials and play an important role in the international market [4].

Unlike traditional wireless capsule endoscopies which are moved passively by natural peristalsis, devices featuring active locomotion are capable of being remote controlled and orientated. Generally two different designs have been investigated in this area: internal locomotion, which is based on the on-board integration of a miniaturized locomotion system, and external locomotion, which is actuated by the interplay between internal and external magnetic fields. Both of these approaches have been partly adopted or proposed for development in the current and future generations of capsule endoscopy [4].

2. WCE systems

A wireless capsule endoscopy system, as shown in Figure 1, comprises 3 hardware components: an electronic capsule, which is used as the image recorder and transmitter; a receiving box outside human body, and an image processing station including specialised software [1]. Based on these hardware components, several independent modules are further allocated to realize the functions of the WCE: locomotion, vision, telemetry, localization, power and manipulation tools [4].

Considering physiological and security issues, biocompatible materials are suggested in the fabrication of the capsule shell. The technology of the optical lens and image sensors of the camera directly influence the quality of the captured images and consequently are always one of the major concerns of researchers. In the current stage, most lenses merely have a fixed focal length which is definitely not sufficient to deal with the complicated environment and various human tissues [4]. CMOS and charge coupled devices are 2 mainstream technologies applied in most image sensors. They are selected accordingly to balance between obtaining high-fidelity images and enhancing high-cost performance. Also, since there is no light source inside the human body, a design that can provide the minimal light requirements is imperative [6]. Unlike traditional endoscopy which utilizes optical fibers for light delivery, flashing LEDs are adopted in WCE systems. The batteries used in the WCE basically have 2 properties: high energy and small size, hence, current WCE's are developed on lithium ion polymer technology, 3-D thin film battery technology and miniaturization [4]. A future power system solution currently under investigation is to use wireless power transmission via magnetic field induction.

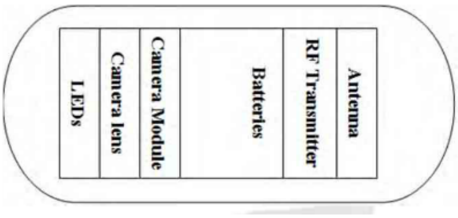
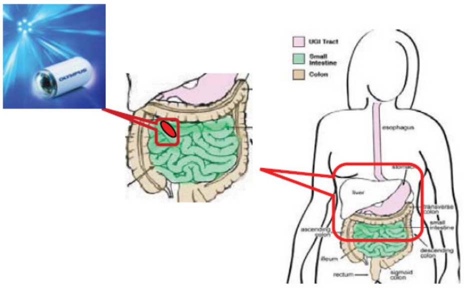


Fig. 1. the framework of WCE [5]



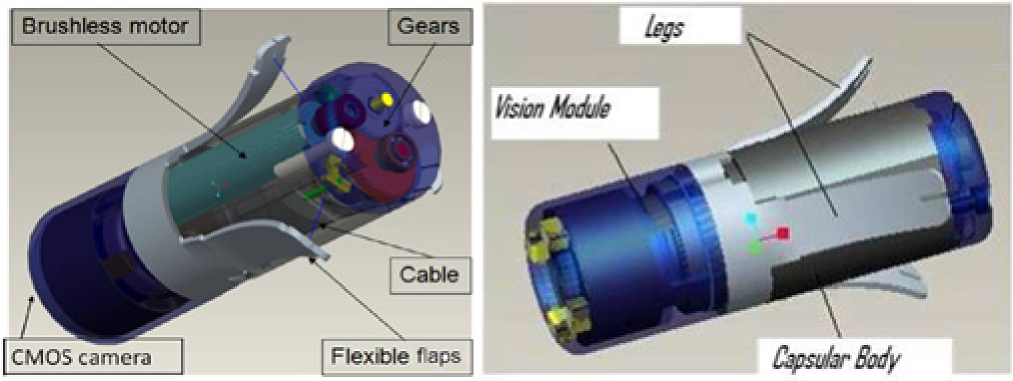


Fig. 2. a novel anchoring design for wireless capsule endoscopy [7]

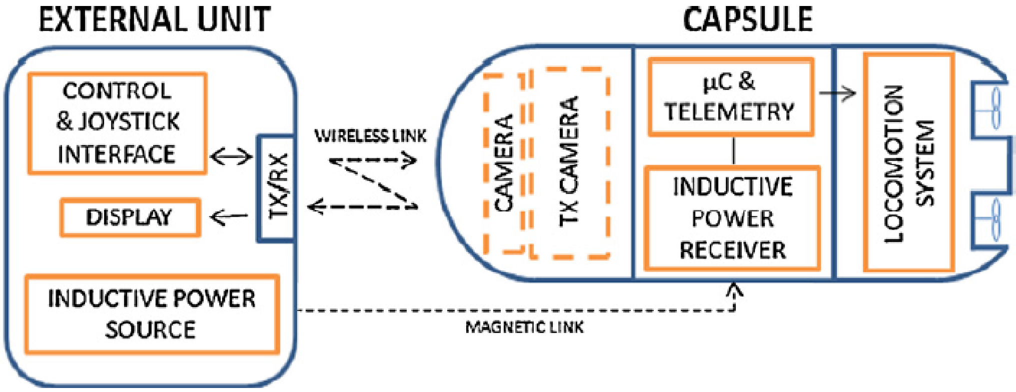


Fig. 3. connections among different modules in the submersible WCE

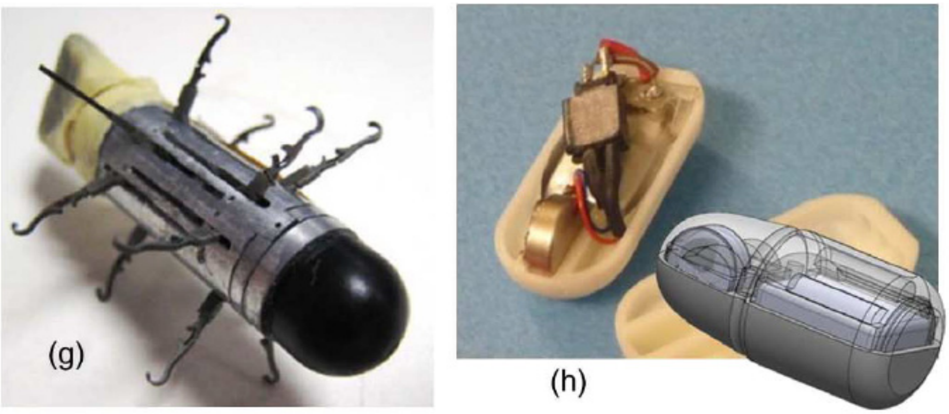


Fig. 4. WCE with SMA legs and WCE with vibratory actuator

3. Internal locomotion

As a WCE passes through the esophageal tract, it is propelled by gravity and natural peristalsis. This happens rapidly, often too rapidly for high quality images to be captured. Consequently, it is important to be able to slow this movement down and provide sufficient time for images capture. Increasing frame

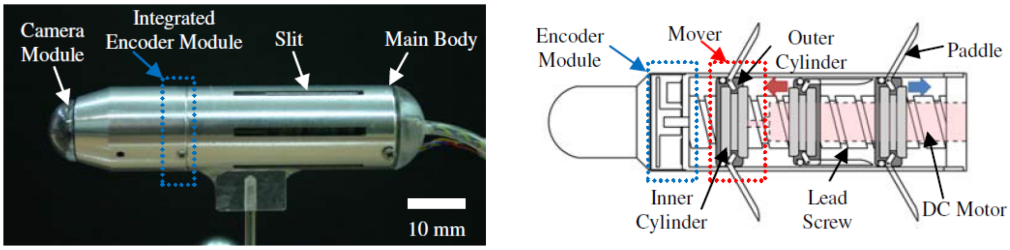


Fig. 5. schematics of a paddle-based WCE

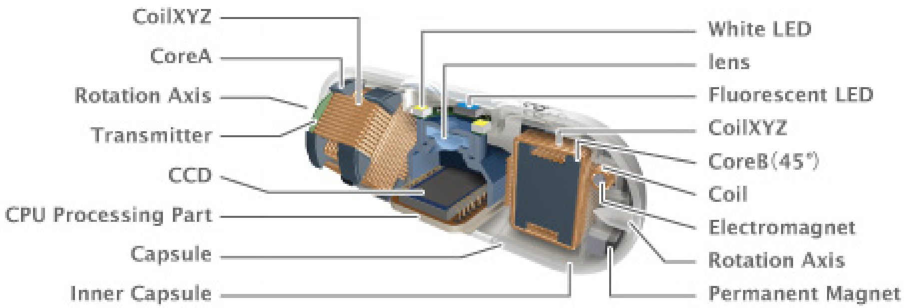


Fig. 6. RF System Lab-Sayaka

capture rate aids in this; however, that places more restrictions on the camera design and hence on the entire design, including size, cost and even working principles. [4]

An innovative stopping mechanism reported by Tognarelli, et al. offers a different solution to this issue. As illustrated in figure 2, to fight against the peristaltic forces of the esophagus, 3 flexible flaps made of Shape Memory Alloy (SMA) are positioned around the capsule shell to offer controllable friction. Moreover, strain gage-based force sensors and an electromagnetic direct current brushless motor is added to complete the whole system. The dimensions of the device are larger than some others with a diameter of around 11 mm and a length of 31 mm, but still of ingestible size [7].

Stomach inspection had been the dead corner of traditional capsule endoscopy for a long time due to the complex liquid-filled environment of the stomach. An impressive miniaturised submarine system proposed by Carta, et al. offers a potential solution to this problem. The device is powered via a wireless supply utilising a magnetic inductive connection between the power source within the capsule and the external supply. The received power is amplified and used to drive the operation of the locomotion system, as depicted in Figure 3 [8].

The active locomotion module of the system comprises 4 adjustable DC motors. The operators can maneuver the capsule within the stomach by controlling the working state and rotating speed of the motors. The prototype used at the research level is 15 mm in diameter and 40 mm in length, where more than half of the overall volume is required to house the power receiving and locomotion modules. Despite of the size limitations, the conditions on power consumption are acceptable at under 400 mW. The liquid used for testing was polyethylene glycol (PEG) which has a density of 1105 kg/m3 to provide neutral buoyancy. Additionally, this liquid also has a positive collateral effect to ease the pain of the patients. For practical considerations, the weight of the device needs to be chosen dependant on the properties of the liquid, this

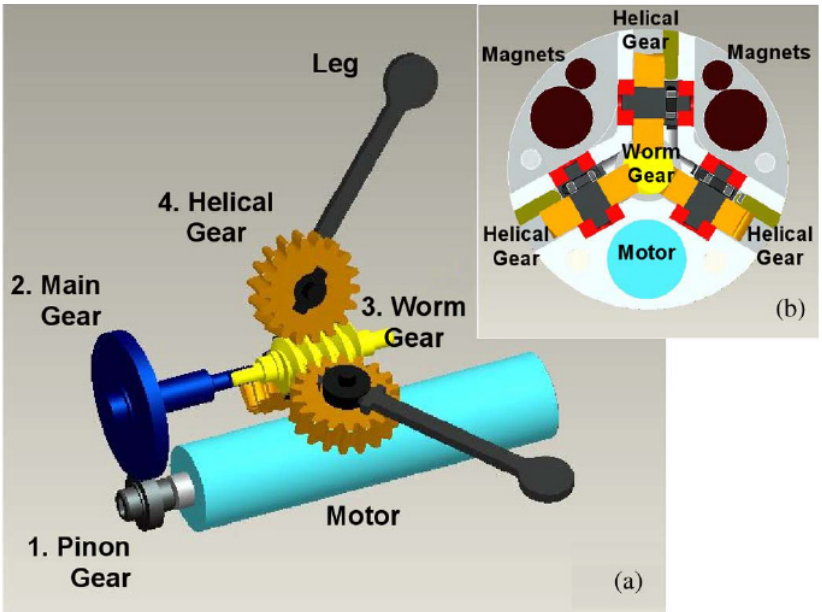


Fig. 7. an overview of the inner mechanism

leaves some uncertainty for this approach [8].

Unlike the WCE used for stomach inspection, intestinal capsule endoscopy is based on the design of an anchoring mechanism. One such system employs an additional set of SMA legs to those used on the oesophageal WCE, which are able to imitate a crawling motion. An enhanced efficiency and stability have been demonstrated by increasing the number of SMA legs [4]. Another system is a worm-like capsule proposed by Kim et al.; using a cyclic compression/extension SMA spring which is able to provide a passive anchoring system without any demand on actuators or power supply. However, this approach is greatly restricted by its incapability to control capsule orientation. This type of limitation also prohibits the clinical realization of the WCE propelled by vibratory actuator, which can reduce friction between the capsule and the environment through frequency controlled vibration.

Besides SMA-based “legs”, paddle-like motion is another highly promising strategy. Illustrated in Figure 5, different situations confronted by the capsule are translated into pins, these signals are decoded by the encoder module and used to control a DC motor that can change the status of the paddles. The paddles can be extruded or folded from the module to control motion as required. The feedback sensor collects data including speed and phase differences, which helps operators to monitor the condition of the capsule and manipulate it accordingly [9].

4. External Locomotion

In comparison to internal locomotion, external locomotion works using the interactions between inner and outer magnetic fields, without the presence of actuator modules. This framework has a great advantage in size. Both permanent magnets and electromagnets are adoptable, depending on requirements. This leaves considerable flexibility for design and manufacture.

RF System Lab, Japan, has been conducting research aimed at combining wireless power transmission and external active locomotion techniques into the traditional WCE since 1998 and consequently, they lead the industry in this technology. The Norika capsule, designed by the Norika Project Team, RF system lab, is the first magnetically controlled capsule adopted for clinical use. Moreover, it also represents the best miniaturized architecture of the time: the device is only 9 mm in diameter and 23 mm in length. 3 external electromagnets, which acts as rotor coils, correlate with the internal electromagnetic rotor coils to detect the rotation of the capsule within the GI tract. [10] Several generations of the Norika capsule has been released by the company during the last decade, including a specially designed WCE for children and a versatile WCE robot. The latest endoscopic capsule produced by RF System Lab, the Sayaka, is aimed at capturing the whole inner surface of the long digestive tract as shown in Figure 6. The equipment features an advanced image processing system able to continuously magnify and reconstruct images which it can then restore into a tube shaped version. [11]

Similarly, Chongqing Jinshan Science & Technology, China, developed a magnetic induction powered capsule named OMOM. The device was designed with an on-board permanent magnet which interacts with the disk-shaped permanent magnet controller installed in the operating table during the diagnostic process. [12].

5. Honybrid locomotion

Hybrid locomotion is defined as a combination of internal locomotion modules and external magnetic navigation. For example, in the proposal presented by M. Simi et al, an internal legged mechanism is actuated to help the capsule overcome some collapsed GI tract regions. Integrating both locomotion technologies increases complexity and poses a big challenge in miniaturization. However, the enhancement in working efficiency is also considerable.

The design of M. Simi et al can be considered from two separate aspects of motion. The on-board legged internal mechanism is activated when the capsule is stuck in some regions in the intestine. In detail, the open legs can be used together with the external magnetic fields to provide the capsule with a lever-like action and push it out of any regions of collapsed tissue. In addition, the legs can be used to aid in the dilation of the lumen thus achieving a better view. The mechanism is illustrated in Figure 7 [13]. The magnetic system propels the capsule for most of the time during its journey. Interestingly, instead of human operators, a robotic arm featured with a cylindrical NdFeB N35 permanent magnet is utilized to steer the device[13].

6. Conclusion and Future Work

With the advance technology in miniaturization and active locomotion, WCE looks set to play a bigger role in GI tract inspections. Although many investigations remain at the lab level, the coalition of all of these subtle improvements leads to a high degree of expectation for the future. At the same time, from a patient care perspective, the improved capability in conducting therapeutic tasks offers a more comfortable alternative to techniques currently in use. Cost reduction and improvements in small scale fabrication will also contribute greatly to the promotion of the WCE and the technique will eventually become a regular weapon in handling GI tract diseases.

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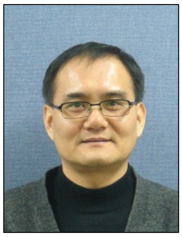

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