Wireless Capsule Endoscopy

Eng Gee Lim, Jing Chen Wang, Zhao Wang, Tammam Tillo, Ka Lok Man and Nan Zhang

***Abstract*—Wireless capsule endoscopy (WCE) is a technique in which an ingestible electronic diagnostic capsule capable of working wirelessly is swallowed. It is superior to traditional endoscopy as WCE lacks all the limitations of traditional wired diagnostic tools, such as cable discomfort and the inability to examine highly convoluted sections of the small intestine. This paper reviews historical developments of this technique and state-of-the-art WCE designs. Main features of existing devices are also investigated in terms of their diagnostic capabilities and limitations, as well as hardware designs. Current research and potential directions to improve WCE technology are discussed.**

***Index Terms*—Electronic diagnostic device, small intestine, WCE.**

I. Introduction

THE organization American Cancer Society reported that the number of cancers related to the gastrointestinal (GI) tract amount to 149,530 in the United States in 2010 [1]. In most of these cases timely detection and diagnosis are extremely important since the majority of GI-related cancers caught in the early stages are curable.

Gastroscopy is typically used for the diagnosis of the upper gastrointestinal tract which includes the esophagus, stomach and duodenum. It is a technique in which a long flexible tube equipped with a CCD or fiber-optic camera is inserted into the oral cavity for diagnosis, surveillance, and diagnostic verification of biopsy procedures, as well as therapeutic interventions. For colon and rectal examination, colonoscopy may be employed. The basic working principle of colonoscopy is similar to gastroscopy; however, it is passed through the anus. Gastroscopy and colonoscopy allow the coverage of two important areas of the gastrointestinal track. However, the small intestine, which represents most of the digestive tract, lies beyond the reach of the two aforementioned techniques.

The small intestine in the GI tract is characterized by being very long (average length is 7 meters) and very convoluted. Therefore, the non-invasive Wireless Capsule Endoscopy (WCE) technique was proposed to enable visualization of the entire GI tract. This paper outlines the main features of existing devices, in terms of their diagnostic capabilities, limitations and hardware designs.

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II. The WCE System

Development of WCE began in the early 1980s and it is still ongoing, passing through the crucial moment in 2001 when it was approved by the U.S. Food and Drug Administration (FDA). The wireless capsule endoscope, as an ingestible capsule, is able to take pictures during its course through the digestive tract including the stomach, large bowel or colon and part of the small bowel after being swallowed. Accordingly, the WCE communication system requires the transmitter to consume minimal power, to be minuscule, and to be optimized for signal transmission through the human body. Fig.1 shows the typical components within an imaging capsule system with dimensions 11 mm × 26 mm [2].

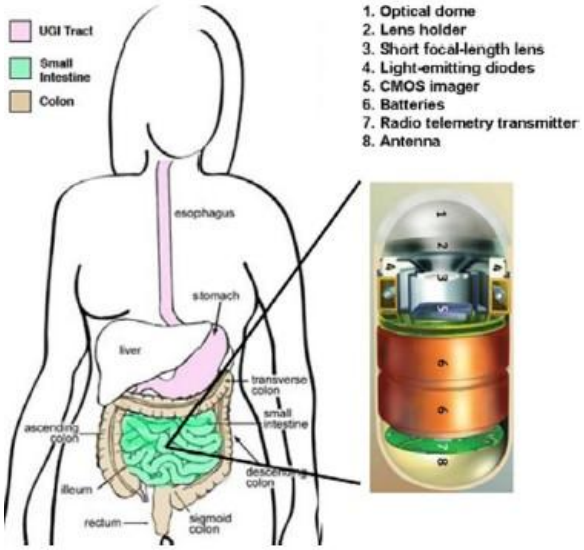

Fig.1. Biotelemetric imaging capsule components

The capsule endoscopy system is composed of several key parts (shown in Fig.1): image sensor, lighting, control unit, wireless communication unit, power source, and mechanical actuator. The imaging capsule is pill-shaped and contains these miniaturized elements: a camera lens, a CMOS imager, batteries, LEDs and an antenna/transmitter. When it is used, the capsule records images and transmits them to the belt-pack receiver. The capsule continues to record images at a very high rate over the course of the 7 to 8 hour image acquisition period, yielding a total of approximately 55,000 images per examination. Receiver/Recorder Unit receives and records the images through an antenna array consisting of several leads which are connected by wires to the recording unit, worn in standard locations over the abdomen, as dictated by the template for lead placement [3].

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The most popular WCE systems are developed and manufactured by Olympus [4], IntroMedic [5] and Given Imaging [6]. However, there are still several drawbacks limiting the application of WCE. There have been two main goals with regards to WCE development. One is to reinforce the advantages of current wireless capsules, such as creating a smaller capsule, enhancing propagation efficiency of the antenna or reducing radiated effects on the human body. Others are working on minimizing the disadvantages of capsule endoscopy, like using internal and external magnetic field to control the capsule or IC technology to reduce power consumption.

III. The WCE challenges

This section outlines the major challenges limiting the use of WCE. These limitations include the long examination times which vary from 45 to 180 minutes per patient, which means there may be delays which limit the number of patients who may benefit from the service. Another limitation is short of battery life, which may necessitate the capture of small image resolution with low frame rates. Most of WCE deficiencies are related to the fact that it is a wireless procedure. Consequently, unlike endoscopy, it cannot be used to obtain biopsies or perform therapy, and once swallowed, it cannot be controlled remotely. Images may be limited by transit and position as it moves through the GI tract.

Although WCE has a lot of advantages, there are a number of risks which cannot be simply ignored. WCE is not for everyone and is contraindicated in patients with known or suspected gastrointestinal obstructions, strictures or fistulas, cardiac pacemakers or other implantable electromedical devices and swallowing disorders. In fact, a few cases of capsule retention have been reported in the past, in which the capsule remains in the digestive tract for more than two weeks. There is also a low risk of skin irritation from the sensor array sleeve adhesive or silicone exposure. These risks may pose problems and medical or surgical intervention may be necessary to address any of these complications.

IV. THE FUTURE OF WCE

The current WCE system design is satisfactory but there is room for improvement. A number of issues such as hardware limitation, capsule positioning and locomotion control still needs to be resolved. Current WCE system design issues and research in resolving these issues will be investigated.

Future research trends can be divided into three main categories, namely, positioning, application and hardware improvement. In current WCE systems, the capsule location within the GI tract cannot be ascertained as real-time tracking proves to be challenging. Researchers are trying to find ways to locate the capsule or alternatively, to employ methods of propelling the capsule out of the GI tract.

Providing new applications like therapy or drug delivery through WCE is also a fascinating research trend. Future WCE devices may hold up to one milliliter of liquid or powder, which may be released at a targeted site within the body. It may contains a small amount of gamma-emitting tracer, allowing precise tracking in real time using an external gamma camera. In this scenario, when the capsule reaches the target area, an external electromagnetic field actuates the capsule's piston, ejecting the payload. The shell then passes harmlessly out of the body.

Researchers are always trying to make the WCE smaller, lighter and more functional but hardware limitation is a bottleneck to the WCE system. There are numerous proposals to improve current WCE designs, such as replacing the CCD sensor with CMOS, improving light sensitivity, controlling frame rate, as well as managing power consumption.

V. Conclusion

WCE was invented due to demand for detailed investigation of the GI tract. It solves many a number of issues posed by preceding technologies. Since its inception in 2001, WCE has become a promising technology with great potentials. The WCE device has an array of sensors working together as a cohesive unit and system that can be operated outside the human body. Improvement in the technology is still ongoing with the size of the capsule getting smaller and the components becoming more efficient. Companies and individuals are still aiding its development, performing optimizations and adding new features.

This paper has delved into the historical development of WCE and reviewed state-of-the-art WCE designs. In addition, features of existing devices were examined in terms of their diagnostic capabilities and limitations. Finally, research trends were briefly discussed along with possible improvements which may find their way in future WCE devices.

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