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Past, Present and Future of Robotic Capsule Endoscopy

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Abstract:

A capsule endoscope is a swallowable remote little camera for getting pictures of the gastrointestinal (GI) mucosa. The underlying capsule endoscope model was created by Given Imaging and affirmed in Western nations in 2001. Prior to the presentation of capsule endoscopy (CE) and double-balloon endoscopy (DBE), there was no powerful methodology for the assessment and the executives of patients with obsure GI bleeding. Obsure GI draining is characterized as seeping of obscure birthplace that endures or repeats after a negative beginning or essential endoscopy (colonoscopy or upper endoscopy) result. The main capsule endoscope model, which is currently viewed as a first-line device for the discovery of variations from the norm of the little entrail, was the PillCam SB. It was endorsed in Japan in April 2007. The principle sign for utilization of the PillCam SB is obsure GI bleeding. Nearly the solitary difficulty of CE is capsule maintenance, which is the capsule staying in the stomach related parcel for at least fourteen days. A held capsule can be recovered by DBE. There are a few impediments of CE in that it can't be utilized to acquire a biopsy example or for endoscopic treatment. In any capsule, the mix of a PillCam SB and DBE is by all accounts the best methodology for the executives of obsure GI bleeding. As of late, a few new sorts of capsule endoscope have been grown, for example, Olympus CE for the little entrail, PillCam ESO for examination of esophageal illnesses, and PillCam COLON for identification of colonic neoplasias. Sooner rather than later, CE is required to positively affect numerous parts of GI illness assessment and the executives.

Keywords -application-specific integrated circuit, charge-coupled device, capsule endoscopy, computer topography, gastrointestinal

1. Introduction

Ingestible robotic wireless capsule endoscopy, also known as Wireless Capsule Endoscopy (WCE) was introduced in the year 2000 [1], with the initial model developed by Given Imaging Ltd. This Israeli group obtained clearance from the United States Food and Drug Administration (FDA) in August 2001 [2]. WCE is a minimally non-invasive way of screening or inspecting the gastrointestinal (GI) tract without sedation and discomfort. It is in the frontline amongst the promising technologies assisting the future of medicine and to save the lives of people [3], [4] who could not bear the screening drawbacks of wired traditional endoscopy such as laparoscopy and colonoscopy which takes longer time in the examination process, painful, puncture or tear of the walls of the intestine and difficulty in breathing [5].

Due to the drawbacks mentioned earlier of the traditional endoscopy, there was a need to develop WCE which consists of a wireless miniature imaging camera that can capture and transmit video images at two frames per seconds. As the capsule swallowed, it takes images of the GI tract as it navigates the oesophagus passing through the stomach and small intestine down to large intestine and later reflexively defecated from the body. The entire track inspected for related mucosal diseases like the Obscure Gastrointestinal Bleeding (OGIB) [6], tumours, Chron's and celiac diseases [6], [7]. The captured images are transmitted digitally to the recorder worn like a belt around the patient's waist. After eight hours, clinicians can cross-examine the video data for results in approximately two hours [8].

In the fullness of time, WCE will be controlled or guided externally by the magnetic actuator to ease its orientation and locomotion [9], microgripper attached for polyp removal [10], drugs delivery at a targeted point [11], [12], the quality of images improved, the number of captured images reduced to save analysis period, controlled actively and biopsy for tissue surface mapping and localisation [10].

Consequently, this dissertation focuses on the past, present, and future advantages of ingestible robotic wireless capsule endoscopy.

2.Overview of ingestible wireless robotic capsule endoscopy

2.1 Origin of ingestible wireless capsule endoscopy

After the first attempt made by Philipp Bozzini on endoscopy capsule in 1806 [13], Senior engineer, GavrielIddan who was on sabbatical from the Israeli Ministry of Defence went to Elscint company in Boston, USA, during his stay he studied X-ray and medical imaging in 1981 [14]. During his research with his friend Eitan Scapa, an Israeli gastroenterologist [14], Iddan observed that fibre optics could use the inspection of the gastrointestinal tract, but the gastroenterologist explained to him that is possible, but it cannot reach or inspect the small bowel because of its length and nature of the bowel. This been a challenge for Iddan, ten years later, he thought of using a small Charged-Coupled Device (CCD) and connecting its camera which is very small to the electrical umbilical cord [14], [15]. It generated more problems like the high consumption of energy, controlling the capsule's locomotion, cleaning the surface of the camera lens and time taken for doctors to screen the patients' images.

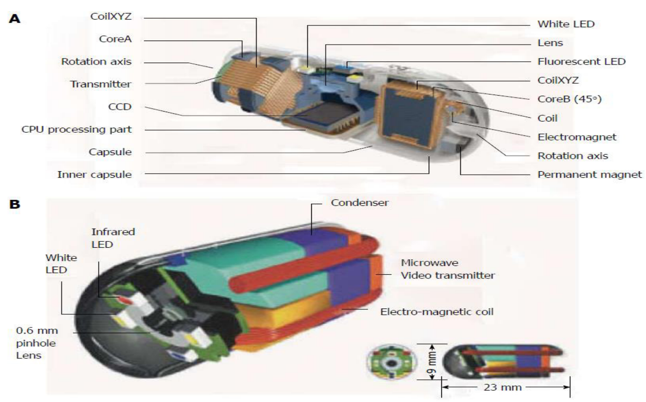


Figure 2.1 Initial prototype of ingestible robotic capsule endoscope with CCD [16]

Capsule A, (Figure 2.1A) is NORIKA 3, submarine-like WCE and developed in 1997 [16]

Capsule B. (Figure 2.1B) is SAYAKA, is the first capsule without battery announced in 2001[16]

With the problems at hand, Iddan in 1993 decided to split the capsule configuration into three different parts namely,

Part 1: The camera and transmitter section[17]

Part 2: The receiver worn like a belt on the patient's waistline [18]

Part 3; The computer system to view the captured images [14], [19]

With the problems highlighted, a team of engineers and researchers were interested in solving the issues with power consumption and low frame resolution [20] and realisation of the capsule was prevented by limits in available technology [21]. At that time, the

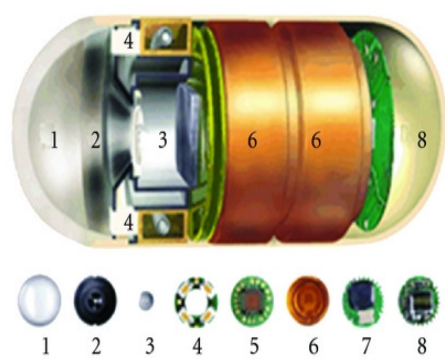
CCD imager which primary function was to transfer charges generated by a process called photoelectric conversion via bucket relay [22]. Nevertheless, the CCD at their disposal drained the battery faster than expected because it consumed more of its power as it travelled down the GI tract. With the Light Emitting Diodes (LEDs) for illumination and the invention of Complementary Metal Oxide Silicon (CMOS) whose imager can convert the charge into voltage and at the same time light to electronic signals. Despite the signals generated were initially weak but later amplified [23], they could minimise the power issue, and the low frame rate managed by designing an ogive shaped lens to remove reflections internally [21]. With these CMOS, miniaturised LEDs and Application-Specific Integrated Circuits (ASIC) researchers could realise the dynamics and made advancements in the capsule. With special thanks to Iddan's patient, Giving Imaging Inc. introduces the ingestible wireless robotic capsule that moves along the track by peristaltic contractions [6], [21], [24].

With this latest development made in Israel, live images were sent from pig's stomach by Paul Swain in the United Kingdom who experimented independently [14]. In the presence of the 8-10 members of the Giving Image team, Paul Swain was honoured to be the first human in the world to ingest the capsule endoscope in October 1999 at Dr Scapa's office [14]. The capsule remained in his stomach for more than three hours until Scapa inserted an endoscope which moved the capsule into the duodenum (small intestine) without sedation, working prototypes were produced in January 1999 by the Given Imaging research and development group headed by Dr ArkadyGlukhovsky [14]

This led to the approval of the first clinical capsule, M2A (also known as mouth to anus capsule and the name later changed to PillCam SB [19], [20], [24], [25] by the United States Food and Drug Administration (FDA) in August 2001 [2].

2.2 Relationship between WCE and GI Tract.

GI tract consists of the colon, small intestine, stomach and oesophagus [26]. An adult GI tract is 8 meters approximately with the convoluted small intestine measuring 5-6 meters in length [27],[28], oesophagus measures about 30cm [6] and colon, 1.5m long and 6.5cm in diameter [29] which is easy for the traditional endoscope to access [6] [30].



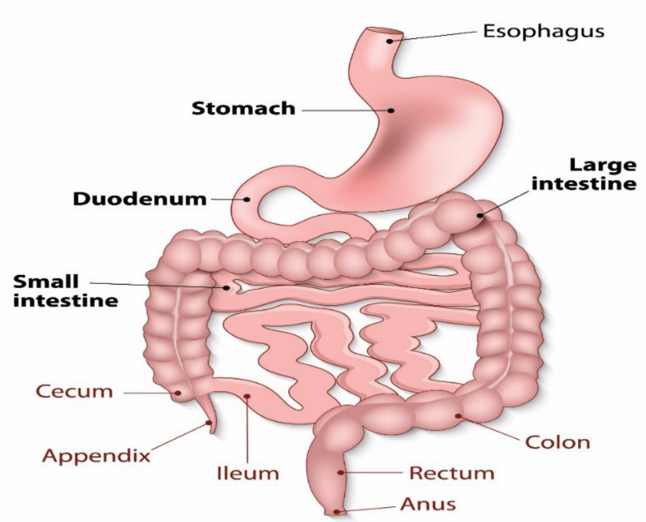


Figure 2.2 Human Gastrointestinal Tract [26]

2.3 Present-day ingestible robotic wireless capsule endoscopy

When the WCE is swallowed, it moves passively by naturally peristaltic. WCE system consists of four parts, (Figure 2.3 a-c), (a) the capsule, (b) image recording belt and (c) the workstation (d) data recorder belt [6][31]. During movement, images are captured, and it uses the LEDs as a light source for the CMOS image sensor [32]. The images are transmitted by ASIC chip [33] to the receiver worn by the patient. The image transmission depends on the manufacturer, like the MicroCam, the images are transmitted via human body communication were human tissues are used as a conductor for the electrical field generated by the capsule [9]. After a few hours, the images are retrieved and processed in the workstation computer [1], [20].

Modules of the entire WCE system

1. Optical dome
2. Lens holder
3. Lens
4. LEDs
5. CMOS imager
6. Battery
7. ASIC receiver
8. Antenna

Figure2.3(a) A typical(M2A)WCE,embedded with the components 1-8 above [6]M2A.

(Figure 2.3a) describes the various components in its internal design. Ranging from the CMOS image sensor in combination with LEDs and lens for images capture, ASIC transceiver for transmission using the antenna attached to it to send the image data down to the receiver, and the power unit which contains two batteries, the receiver sends the signals to the leads to know the location of the capsule.

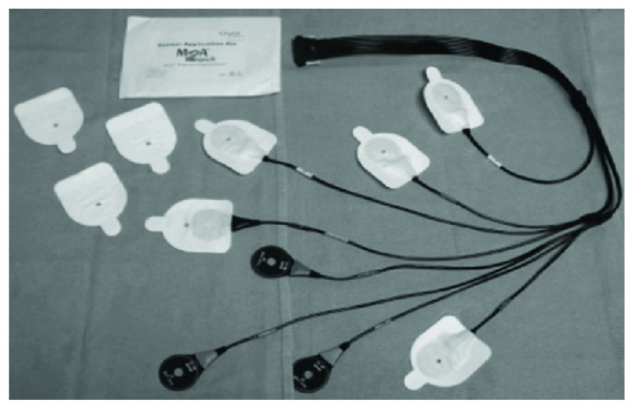


Figure 2.3 (b) The recording unit for images [6]

The recording units, consists of data recorder belt and sensory leads (sensory leads shown in Figure 2.3b above) consists of 8 tips or antennas with disposable sensors which are attached to patient's skin according to the manufacturers' specifications. These leads are used to know the capsule's actual location wirelessly [6], [31].

Data Recorder Belt is linked to the sensors by coaxial cable to receive signals sent by the capsules. This recorder belt comprises the receiver, a hard disk to store the data and a section that processes the leads [31]. The recorder belt's feedback path is the blinking blue light to indicate the dedicated connectivity between the leads sensors and capsules and to show the recorder is recording data [31].

Figure 2.3c. The computerised workstation [6]

The workstation shown in Figure 23c receives the hard disk drives, processes the data stored, and outputs it in video or picture format. It helps physicians to view the video slides in frame usually in 1 to 50 frames per second, and there is an option for playback [25], [34], [35].

2.4 Application of wireless robotic capsule endoscopy

Notwithstanding the high cost of the capsule presently, there is potential for a price reduction when there is an increase in demand for capsule endoscopes. WCE can be used to diagnose or in some cases help doctors to determine possibilities for reoccurrence of the following GI tract related diseases

2.4.1 GI tract bleeding

Bleeding in the GI tract can be divided into active and inactive, and it may be seen anywhere in the GI tract [36]. Active bleeding refers to proof of evolving bleeding, while the idle or slow bleeding refers to bleeding after an endoscopy have been performed [37],[38]. These two types of bleeding are also known as OGIB. When bleeding persists Double-Balloon Enteroscopy (DBE) which is an option for OGIB, or Computer Tomography (CT) can be applied to locate the actual bleeding spot instead of Capsule Endoscopy (CE) only [31], [36], [37], [39].

2.4.2 Ulcer

It is another type of small bowel disease, and it can be detected using related visual properties like the colour, shapes and textures [40]. The ulcerous region shows apparent variety in terms of colour if analysed with haemorrhage and its surroundings [39],[40]. Therefore, images captured by the WCE can be analysed based on the information from the pixel and frame with an advanced algorithm.

2.4.3 Polyp

The polyp is formed when tissue grows abnormally from a mucous membrane and form a lump. It could lead to colorectal cancer if left untreated. The number of people with this most common cancer has increased because the traditional endoscopes find it challenging to access the small intestine but use radiological devices which is not as accurate and lower sensitivity when compared with CE.

Other areas were WCE is very useful are in diagnosing **Crohn's disease** (inflammation of the lining of the digestive system, identified by Dr Buril Crohn in 1932) [35], [36], [41], **celiac**

disease (inflammation of the small intestine) [38], [42], [43], **oesophagus** and **colon diseases**[44]–[46].

3. Ingestible robotic wireless capsule endoscopy of the future.

Based on the existing technologies of the current WCE, there are still limitations and shortcomings. The major drawbacks of the present capsule:

1. it uses passive movement in the GI
2. it is not easy to track position and localise the orientation in the three coordinate plane
3. delivery of drugs to a targeted point occurs
4. Tissue issue extraction for analysis and power [1], [16],[4].

Movement

Active locomotion of the capsule is divided into two, namely, internal and external locomotion. Internal locomotion is the tendency for the capsule to crawl through the lumen, earthworm-like actuation and navigating the convoluted stomach [1]. External locomotion is when a magnet controls the capsule locomotion. Been that as it may, the mechanical actuator may be limited by the size of the capsule which manufacturers want to make swallowable and the on-board power to maximise space. So, there is a need for energy storage [47]–[49].

Position and localisation

It is straightforward for the gastroenterologist to receives images as the capsule goes down the track but is often difficult and impossible to retrieve the actual location of the capsule except by Radio Frequency (RF), CT and ultrasound [50], [51]. Knowing the area can facilitate playback and drug delivery. In the future, there is need to provide a closed-loop path that helps in the actual position of the capsule. Because the calibration of the sensors on the body can never be relied upon. Since is subjected to errors due to calibration and body movement [47].

Captured images

The major challenge of the present WCE is the quality of these images transmitted because it uses low power and less complexity [52], [53]. In the future, there is a need to use a compressor that can save power since a more significant number of powers consumed for transmission of images to the data logger.

Biopsy

Presently available capsules can only monitor and examine diseases in the GI tract. The tendency to perform the surgery has been on the experimental desk and is not feasible clinically. The regulatory body did not accept Crosby-Kugler biopsy capsule [10], [50]. Because the capsules forceps could not hit the targeted tissue, the workspace and size of the forceps were not visible by the camera, and the grippers could open just once [10], [38], [42], [50]. In future, there is a need to incorporate micro-gripper to enable drug delivery and polyp removal[10], [54].

Conclusion

Iddan and Scapa invented the first approved ingestible robotic capsule endoscopy to minimise the invasive traditional endoscopy methods, also known as wireless capsule endoscopy. The FDA did approval in 2001. The drawbacks of the traditional endoscopes were pains, sedations, inability to access the small intestine.

As explained in chapter 2, the ingestible robotic capsule comprises a lens, LEDs, battery and CMOS image sensor. The capsule transmits the gastrointestinal (GI) tract images via the image sensor to the receiver worn by the patient. The image data are stored in the hard disk drive in the receiver; the eight sensors on the patient body are to locate the position of the capsule in the GI. The gastroenterologist later removes the hard drive, and the data is analysed in the computerised workstation.

As explained in chapter 3, there is a need for technological advancements to overcome the shortcoming of present-day WCE to solve power, localisation, active locomotion, sensing, biopsy and drug delivery.

This dissertation concluded that shortly there would be a reduction in the cost of WCE. Moreover, with the increase in the majority of work done there will be improved quality, eroding the supremacy of traditional endoscopy, and it will become the only teleoperated and screening tool for GI tract related diseases [55].

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