Recent Patents on Wireless Capsule Endoscopy

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Abstract: Wireless capsule endoscopy is a medical procedure which has revolutionized endoscopy as it has enabled for the first time a painless inspection of the small intestine. The procedure was unveiled in 2000 and is based on a vitamin-size pill which captures images of the digestive tract while it is transported passively by peristalsis. The device consists of an image sensor, an illumination module, a radio-frequency transmitter and a battery. Wireless capsule endoscopy is a novel breakthrough in the biomedical industry and future progresses in key technologies are expected to drive the development of the next generation of such devices. Therefore, the purpose of this review is to illustrate the most recent and significant inventions patented from 2005 to present in those areas concerning measurement of human body parameters, advanced imaging features, localization, energy management and active propulsion. Finally, the manuscript reports a discussion on current and future developments in wireless capsule endoscopy.

Keywords: Wireless capsule endoscopy, capsule endoscopy, robotic capsules, active locomotion capsules, self propelled capsules.

INTRODUCTION

Wireless capsule endoscopy (WCE) is a procedure which has enabled for the first time a painless diagnosis inside the gastrointestinal (GI) tract. It was unveiled at the Digestive Disease Week 2000 by Swain and Given Imaging (Yoqneam, Israel), the company which first marketed this device [1,2]. The pill received approval from Food and Drug Administration (FDA) and was conceived for the inspection of the small intestine mucosa, in particular for the management of GI bleeding, Crohn's disease, celiac disease and small bowel tumours.

The examination requires patients to ingest, after a one night fast, a vitamin-size pill which is carried by peristalsis through the digestive tract. During the transit, the pill takes images which are transmitted to an array of antennas placed externally at the patient's abdomen and recorded into a portable storage unit attached to a belt, around the patient's waist.

The acquisition of images takes eight hours and during this time patients are free to conduct their daily activities. The device is expelled naturally after approximately 24 hours, if no complications arise. Then, patients return to the physician's office to deliver the pill and the rest of the WCE equipment to download the images into the physician's workstation for review and analysis.

This painless procedure has recently extended to the screening of pathologies of oesophagus and colon [3].

The success of WCE has sparked the interest among several research groups, in universities and industries, in order to advance the current status of WCE. In fact, at present, the merit of WCE is limited to the visualisation of the GI mucosa, while it is not possible to stop at specific sites of the GI tract for performing biopsy or therapy or for moving independently of peristalsis.

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In this work, a detailed patent survey on WCE is presented, with particular emphasis on the following aspects: measurement of human body parameters, advanced imaging features, localization, energy management, active propulsion and inspection inside the colon. Patents have been obtained mainly from the following patent search engines: the European Patent Office and the United States Patent and Trademark Office [4,5]. In particular the selected patents were published from 2005 to present, with a few exceptions concerning seminal inventions.

CURRENT AVAILABLE DEVICES FOR WIRELESS CAPSULE ENDOSCOPY

An endoscopic capsule is a device made up of components for vision, illumination, power supply and telemetry, as can be seen in Fig. (**1**) which offers an internal sight of the first pill created by Given Imaging, called "M2A™". The body of the pill hosts the following components: an optical dome (1), a lens holder (2), a short focal length lens (3), four LEDs (Light Emitting Diode) (4), a CMOS (Complementary Metal Oxide Semiconductor) image sensor (5), two silver oxide batteries (6), an ASIC radio-frequency transmitter (7) and an external receiving antenna (8).

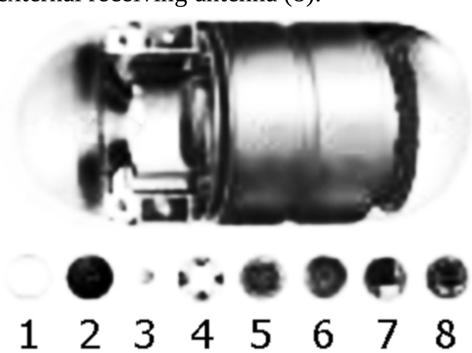

Fig. (1). M2A™ capsule by Given Imaging.

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The first invention in WCE concerns a patent on an *in vivo* camera system and was disclosed by Iddan [6]. The system includes: a light source such as a LED, a viewing window through which the light illuminates the inner portions of the digestive system, a camera system like a charge-coupled device (CCD) which detects the images, an optical system which focuses the images onto the CCD camera system, a transmitter which transmits the video signal of the CCD camera system, a power source such as a battery to provide power to all electrical elements of the capsule, and a data processing system which generates tracking and video data from the single datastream. In particular, the CCD chip includes the camera and the electronics for producing a video signal from the output of the CCD device. The optical system comprises a dichroic mirror and a focussing lens. The mirror transmits the light from the LED to the walls of the GI tract via the viewing window and also deflects the light reflected from the GI tract towards the lens which then focuses the light onto the CCD camera system. The transmitter comprises a modulator receiving the video signal from the CCD camera, a radio frequency (RF) amplifier, an impedance matcher and an antenna. The reception system includes: an antenna array capable of surrounding a body to receive the transmitted video output and to produce a plurality of received signals and a demodulator capable of transforming the plurality of received video signals into a single video datastream.

Up to date more than 500,000 patients have experienced the benefits of WCE and over 600 peer-reviewed journal articles have also been published thereof. Currently Given Imaging sells capsules for the visualisation of the mucosa of the small intestine, PillCam™ SB, and oesophagus, PillCam™ ESO (Fig. (**2**)).

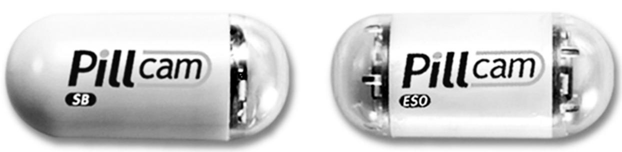

Fig. (2). Capsules by Given Imaging for small intestine (PillCam™ SB) and oesophagus (PillCam™ ESO).

PillCam™ ESO is marketed exclusively in the United States by InScope, a division of Ethicon Endo-Surgery, a Johnson & Johnson company. Both capsules have the same dimensions (26 mm x 11 mm), even if they acquire images at different frame rate: 2 images/sec for PillCam™ SB and 14 images/sec for PillCam™ ESO. This means that, during WCE, PillCam™ SB takes 57,000 pictures while PillCam™ ESO 2,600 by considering the length of the procedure which is, respectively, 8 hours for the small intestine and 15-20 minutes for the oesophagus. Since 2001 WCE has undergone many clinical studies which have proven its efficacy in the diagnosis of obscure GI bleeding which at present remains the main medical indication. In particular WCE was shown more successful than imaging procedures, such as small bowel barium radiography, push enteroscopy, and cross-sectional imaging, including computed tomography (CT) [7]. At present, there is some uncertainty on the role of WCE in the identification of Crohn's disease, while it seems promising in the diagnosis of celiac disease and small bowel tumours [3,8].

On the other hand, during pilot studies PillCam™ ESO has shown encouraging results for detecting Barrett's oesophagus, a disorder which may lead to oesophageal adenocarcinoma, and visualising oesophageal varices [3].

Both PillCam™ SB and PillCam™ ESO are contraindicated in those patients with known or suspected GI obstruction, strictures, or fistulas, swallowing disorders and cardiac pacemakers or other implanted electromedical devices. Furthermore, a serious concern is represented by capsule retention, which may lead to acute small bowel obstruction and in some cases surgery may be required to remove the capsule [9].

In late 2006 Given Imaging disclosed PillCam™ COLON (Fig. (**3**)) for the screening of colorectal diseases and initial clinical tests showed promising results [10,11]. This capsule (31 mm x 11 mm) takes images at 4 frames per second.

Fig. (3). Capsule by Given Imaging for colon (PillCam™ COLON).

The next generation of capsules by Given Imaging will show higher frame rate: 4 images/sec for the PillCam™ SB2 and 18 images/sec for PillCam™ ESO2. Both devices received clearance from FDA in 2007.

A recent market analysis by Millenium Research Group on sales of Given Imaging has proven that the field of WCE is growing at a tremendous pace, as reported in Fig. (**4**).

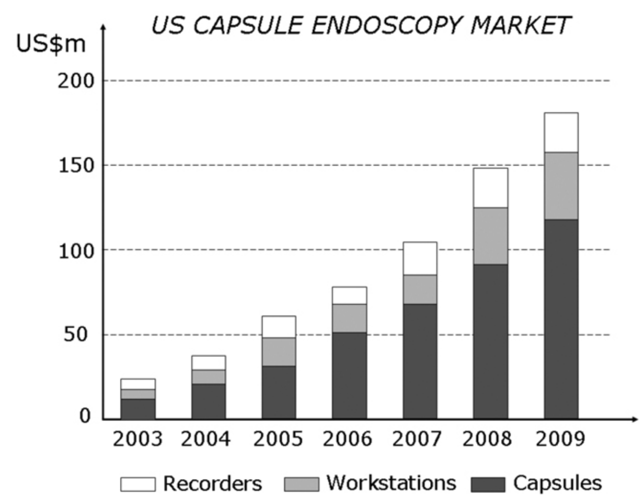

Fig. (4). Trend in WCE market in the Unites States. Source: Millenium Research Group. Medical Industry Intelligence January/February 2005, Volume 1, Issue 1.

For this reason, large companies in the biomedical field are going to enter this market. These include: Olympus, Pentax, Siemens, Fujinon and Fuji. A patents search on WCE of these companies has been performed by using the European Patent Office database. The results are reported in Fig. (**5**).

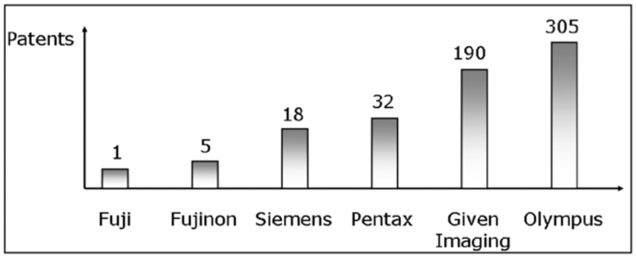

Fig. (5). Major Private Companies' Patents on WCE. Source: European Patent Office. Last Update on September 30, 2007.

The first competitor of Given Imaging was Olympus Corporation (Tokyo, Japan) which disclosed EndoCapsule at Digestive Disease Week 2005, a pill for the inspection of the small intestine. This device (Fig. **6**) has the same dimensions as PillCam™ ESO (26 mm x 11 mm) and frame rate (2 images per second). However it has a CCD image sensor, 6 LEDs for illumination and allows to view the images in real-time [12]. Olympus Corporation has been selling Endo Capsule in Europe since 2005. The device got clearance from FDA in September 2007.

Fig. (6). EndoCapsule by Olympus Corporation for the small intestine.

TECHNICAL LIMITATIONS OF CURRENT DEVICES

A critical limitation of all current devices is represented by the source of power, i.e. a battery. In fact this type of energy source raise relevant issues as to toxicity and time length. In particular, the latter sets a limit on the amount of available energy devoted to the acquisition of pictures. By considering PillCam™ SB, in 15% of cases the early expiration of the battery does not allow to take images of the caecum. Battery length affects also the choice of the image sensor: CMOS technology, used by Given Imaging, or CCD, employed by Olympus. CMOS is preferable since it ensures a lower power consumption than CCD, but at a price of a poorer image quality. With a limited onboard energy it is not possible to add functional tools for several purposes: monitoring of human body's parameters, such as temperature, pressure and transit time to assess motility; stopping the capsule to stay attached at specific points of the mucosa for a prolonged time in order perform tissue sampling; moving actively. In this regard all the endoscopic capsules developed so far by Given Imaging and Olympus are carried passively through the GI tract by peristalsis. If a capsule were able to move actively it could decrease the length of its journey and in particular the time required for an inspection, which is eight hours in the case of the small bowel. Moreover the limited available onboard energy make it impossible to acquire images in all organs of the GI tract, by using one single capsule. Therefore a patient should undergo the examination several times if this procedure were suggested in more than one organ.

In this review authors present those relevant patents which may solve the above reported issues.

RECENT PATENTS ON MEASUREMENT OF HUMAN BODY PARAMETERS

An invention describing an apparatus for measuring electrical characteristics of biological tissue was disclosed by Glukhovsky [13]. Physiological tissues are typified by specific electrical impedance. Since variances in types of epithelial tissue may be recognised by differences in electrical characteristics, changes of this characteristic impedance can provide information about the tissue. For example the early detection of colon cancer may be possible by examining differences in electrical properties of surface epithelium. Other GI pathologies are related to electrical impedance changes, such as Barrett's oesophagus. This invention describes a swallowable capsule with an external surface having openings, a plurality of electrodes located within the openings and a processor in communication with the electrodes for generating electrical characteristics. These include impedance or conductivity values or any other relevant electrical characteristics. This invention includes also a system to transmit the electrical characteristics to a wireless receiver outside the patient's body. The patent describes also a method of measuring a time parameter and distance within the digestive tract.

Glukhovsky *et al.* have proposed a method for sensing the temperature inside an environment, like the digestive tract, by calculating the temperature of an image sensor in the environment and obtaining the environment's temperature from the temperature of the image sensor [14]. The temperature of the image sensor is calculated by measuring the generated dark current noise, which corresponds to the thermal current produced in an operating photodetector device when no optical radiation impinges on the detector. The method for measuring the temperature consists of introducing into an environment an image sensor having an image sensing module, sensing the dark current noise of the image sensor, calculating the temperature of the image sensor and the environment and displaying the calculated environment temperature.

Frish *et al.* disclosed a method to determine motility and/or contracting activities of a swallowable capsule [15]. More specifically, low motility may be caused by an obstruction or a blockage inside the GI tract. Motility disorders may be caused by nervous pathologies and may not be necessarily visible. During its transit inside the intestinal lumen, the capsule may undergo intermittent motion with relative long residence time at some locations. These periods may be normal, because of a change of sections of the GI tract, or due to blockages. Therefore, this invention aims at helping health professionals in monitoring the device motion and in diagnosing and locating areas of blockage or other disorders. In this invention a workstation may be used to process the data once they have been downloaded from the receiver. A processor, internal to the workstation, may determine, measure, calculate and/or analyze motility and/or contractile activity within the digestive tract. By considering a certain amount of images, and hence the time interval thanks to the frame rate, the processor may determine the displacement of the capsule by image comparison in several ways, such as pixel-by-pixel basis. Contractile and motility analysis may be based on a calculation of the difference in a given property between corresponding pixels of two or more, consecutive or non-consecutive, images. Data may be displayed on several windows of the workstation screen. Thus motility and contractile activities may be evaluated. For example the position of the pill may be graphed as a two-dimensional rendering of the three dimensional path. Additionally, the position of the pill may be determined by identifying image parameters typical of a specific region of the GI tract. The capsule may include an accelerometer to determine instantaneous acceleration, while an integrator may convert the acceleration data to velocity data, which may be used by the processor to determine motility and/or contractile activity.

RECENT PATENTS ON ADVANCED IMAGING FEATURES

Davidson proposed a method for determining spatial measurements of anatomical objects for *in vivo* pathology detection [16]. In this invention a data processor analyzes the information received via an external receiver/recorder from an *in vivo* imaging device, e.g. an endoscopic capsule, and is in communication with a storage unit. Data processor may output the analyzed data onto a display, where a user (typically a physician) may view the data. The display may include one or more screens to show images of the GI tract. Moreover, it may show data indicating the position and orientation of the capsule. The display may include a grid or a scale which allows a physician to evaluate specific areas in the displayed image, in particular the size of lesions. This patent illustrates also a method to evaluate an anatomical object viewed by the capsule. In fact, the workstation, which include the processor, storage unit and display, may have a graphics software module to evaluate an anatomical object, whose spatial measurements may be performed on the basis of any measure of a spatial feature, like pixels, frames and bytes. The distance between anatomical structures may be determined by taking into account the focal length of the capsule which varies from 0.5 cm to 3 cm.

Kleen disclosed a medical apparatus for pseudo three-dimensional representation of the surrounding of the capsule endoscope, i.e. the organs of the GI tract [17]. In order to do this, a software merges individual images which show spatially coherent structures by superimposing common images during the image processing procedure. The position and orientation of the capsule are detected during the examination and inserted into the pseudo-three-dimensional representation and visualized onto a display. It is possible to produce different camera perspectives to show different spatial views, for example tissue structures, by influencing two parameters which are the intensity of the advancing movement in the direction of the capsule movement and the intensity of the rotary movement about an axis pointing in the direction of movement of the device.

Davidson proposed a method for editing an image stream captured *in vivo* according to predefined criteria to allow the user, typically a physician, to view certain portions of frames or a short preview in order to save time [18]. A data processor storage unit includes an image database (storing the moving images) and a logical editing database (storing logic editing method) including predefined criteria with rules relating to which selected images, stored in the image database, should be displayed to the viewer. Examples are a selection of rules for displaying one out of hundreds of frames captured, or rules for scanning and selecting pre-determined images pertaining to a known symptom, such as GI bleeding. Predefined criteria indicate logical method/rules that select frames according to a parameter. This may be numerically based, indicating one image in every hundred or two hundred, or quality based, selecting the most qualitative image from each group of images. Editing methods may be combined and employed. The user can also define and create an editing method according to specific needs.

Montalno *et al.* disclosed a method to vary dynamically the field of view of an endoscopic capsule [19]. In particular the capsule includes an optical or acoustical illuminator to illuminate the wall of a GI tract. A scanner, such as a MEMS scanner, may be used to scan the illumination source onto the lining and may be dynamically controlled by a controller. The optical device may consist of other devices like optical lenses, or lenslet arrays to focus the illumination source. The lenslet array may be configured to have a spatially varying focal length and may produce focal spots falling on a cylinder allowing parallel scanning of a curved surface. Other types of lenslet arrays may be used depending on the application. For example, a diffractive lenslet array may be used for illuminating a specific pattern on the scene. The illuminator may also be acoustical, e.g. an emitter of various electromagnetic wavelengths as well as an ultrasound illumination device.

RECENT PATENTS ON LOCALIZATION

Horn proposed a method for determining the path length of an endoscopic pill through a body lumen [20]. According to this invention a recorder may receive signals from antennas and store them temporarily in a portable storage unit. The recorder may include a location detection system which may utilize a triangulation method to determine the location of the pill relative to the antenna array. The triangulation method may be based on the difference in signal strength picked up from the transmitting *in vivo* device by the various antennas in the antenna array. After reviewing the transmitted data, for example the images and/or image stream, a physician may identify a site that may be of interest, for example a location where an *in vivo* device captured an image indicating a pathological area in the GI tract which may need further diagnosis, examination, or treatment. During a following examination and/or treatment with an *in vivo* autonomous device, a physician may want to revisit one or more sites or location points of interest using an alternate device (e.g. endoscope, colonoscope, gastroscope, enteroscope, laparoscope, and another autonomous *in vivo* device, etc). Previous knowledge of the path length may help the physician reach the location point of interest quickly in order to reduce the procedure time and also to lower the patient's discomfort. Additionally, path length may help a physician decide whether it is possible to reach the location point of interest with alternate devices.

Kuth *et al.* disclosed a method for determining position and orientation, by means of X-ray radiation, of an endoscopic capsule, driven by an external magnetic field [21]. In this case the determination of the position and orientation of the capsule is helpful to generate the correct magnetic field for the purpose of capsule navigation. In this invention X-ray radiation is used to reduce the risk of interference with the magnetic field used for navigation scopes. In particular the capsule can be seen unambiguously since it has a multiplicity of radiation-opaque elements which are usually metallic or plastic and show a very clear image. Thus it is possible to operate with an extremely low radiation dose in order to reduce the burden on the patient.

The whole system includes an endoscopic capsule, a navigation device for generating the magnetic field and an X-ray machine for recording radiation images in which the capsule is shown, having an assigned image processing device for automatically determining position and data orientation. The image processing device communicates with the navigation device to transmit the determined position and orientation data. The navigation device includes 14 separate coils that can be individually driven by a control device and, depending on the position and orientation, it generates a magnetic field that acts appropriately at the capsule location and cooperates with a magnetic element inside the capsule.

RECENT PATENTS ON ENERGY MANAGEMENT

Kanazawa presented an endoscopic capsule with a built-in power generator. The power inside the pill is generated by internal coils, while an external power source of a time varying magnetic field supplies energy to the coils [22]. The system is depicted in Fig. (**7**).

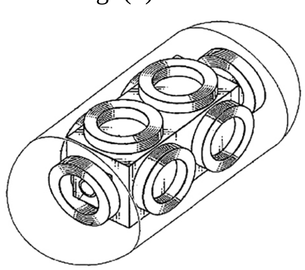

Fig. (7). Representation of the invention of Kanazawa.

By the change of the external magnetic field, each of the coils inside the pill generates electromotive force. The coils have the same annular shape and have the same electric characteristics, i.e. the number of turns and the diameter. The power is supplied to the various components in the capsule. The electromotive forces generated by the coils are also inputted to the comparing circuit, which allows to ascertain the orientations and distances of the coils with respect to the outside power source, so that the attitude of the capsule can be obtained.

On the other hand, the image sensor converts the image formed thereon by the objective lens system to an electric signal which is transmitted to a signal processing circuit. This module performs predetermined processes for the electric signal from the image sensor to generate an image signal. The predetermined processes include a white balance calibration, gamma correction and analog-to-digital conversion. A modulator performs modulating of both the attitude signal and the image one. It acts also as an amplifier. The signals modulated are then transmitted as radio signals via the antenna. The receiver receives the radio signal transmitted from the antenna and demodulates it in order to obtain the image signal and the attitude one. The received signal is then outputted from the receiver to the processing circuit. The processing circuit performs image processing for this signal for the generation of a video signal of the internal body of the patient. The information indicating the attitude of the capsule endoscope may be superimposed on the video picture of the internal body of the patient.

Iddan *et al.* proposed an invention to minimize energy expenditure of the imaging unit of an endoscopic capsule [23]. During WCE, many images have to be acquired in order to cover entirely the considerable length of the GI tract. Additionally, this amount of data may be augmented by redundant images of the same site which are acquired when the capsule stops moving. In this invention the image module is connected to a control unit which includes a switching unit and an axial motion detector connected to the switching unit. The axial motion detector evaluates the axial movement of the device and if the axial acceleration is below a predetermined threshold, it disconnects the power supply thereby preventing the acquisition of redundant images.

Horn *et al.* presented a method to vary the frame rate of images acquisition of an endoscopic capsule [24]. In fact the capsule may move unevenly inside the digestive tract and if it is acquiring images at a constant frame rate, a physician performing diagnosis may experience receiving undesirably more images for a portion of the GI tract than another. According to this invention, the images captured by the capsule may be “regular images”, if transmitted outside of the patient’s body and displayed, or “control images”, if acquired for frame rate control purpose and thus not recorded or displayed. A processor unit may analyze a set of control images to produce a control signal and adjust parameters of image acquisition process accordingly. The control signal may include the rate of image acquisition and/or frame transmission of the acquired images. An adjustment of frame transmission may be obtained by calculating the difference between the calculated moving speed and a reference speed.

Glukhovsky *et al.* proposed a system to receive electromagnetic energy and to convert it into energy to supply power to an endoscopic capsule [25]. The external energy source for induction of the capsule is a magnetic field generator capable of generating a time varying magnetic field around the device. In particular, the magnetic field may either be unidirectional or have three orthogonal components. This magnetic field can be generated by an AC induction coil or by a rotating magnetic circuit. The magnetic field generator may communicate with a localizing device to determine the location of the pill inside the patient's body. The magnetic field generator can then be moved along the patient's body according to the capsule location, thus optimizing the energy transfer from the external energy source to the pill. The energy receiving unit contains a three axial coil assembly and a corresponding selector rectifier circuit able to convert magnetically induced AC voltage to a desired DC voltage available to supply power to the electrical components inside the capsule.

Nakamura *et al.* presented a method to provide an endoscopic capsule with wireless power supply by means of an energy supplying coil sending power to the capsule, based on a magnetic coupling power supply [26] Fig. (**8**).

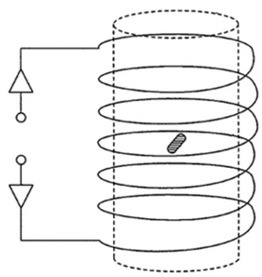

Fig. (8). Representation of the invention of Nakamura.

This invention describes a transmitting/receiving device with functions of both power supplier for transmitting power to the capsule and receiver of image data sent from the pill inside the body. The transmitting/receiving unit can be worn by the patient and consists of an antenna (the energy supplying coil), a set of receiving antennas and an external device which processes transmitted/received radio signals.

More specifically, the transmitting/receiving includes an RF receiving unit that executes a predetermined processing for a radio signal received by the receiving antenna and extracts image data obtained by the pill from the radio signals so as to output the image data, an image processing unit executing a process necessary for the output image data, and a storage unit storing the image data. The transmitting/receiving device includes also specific modules for the generation of a radio signal transmitted to the capsule. These are: an oscillator that generates a power feeding signal and defines an oscillation frequency, a control information input unit generating a control information signal for controlling a driving state of the capsule endoscope, a superposed circuit which synthesizes the power feeding signal with the control information signal, and an amplifying circuit which amplifies the strength of the synthesized signal. The signal amplified by the amplifying circuits is then transmitted to the power feeding antenna so as to be transmitted to the pill.

RECENT PATENTS ON SELF PROPULSION

Kim *at al.* proposed a remote control system for an endoscopic capsule from outside the patient body [27]. The system is equipped with a capsule, a permanent magnet, Hall effect sensors, a 2 degree of freedom (DOF) rotary joint unit for rotating an external permanent magnet, thus applying magnetic forces to the permanent magnets in the capsule, a distance sensor attached to a lower end of the 2 DOF rotary join unit to evaluate the distance between the external permanent magnet and the surface of the human body, a Cartesian coordinate robot to move the external permanent magnet and the 2 DOF rotary joint unit, and a bed to support the patient Fig. (**9**).

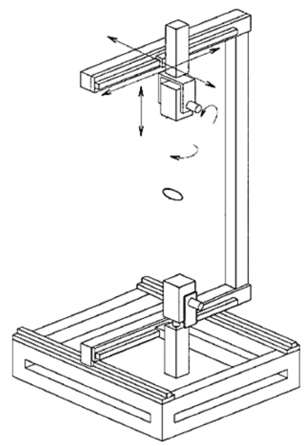

Fig. (9). Representation of the invention of Kim.

The Hall sensors provide information on the magnetic force applied to the capsule and the distance between the capsule and the external permanent magnet. Signals of the Hall sensors are transmitted to the remote control unit outside the human body via the wireless transmission circuit, together with an image signal of the camera.

The scope of this invention is to realize a remote control system enabling an endoscopic capsule to move, rotate and stop in the digestive tract. Another scope is to prevent an excessive magnetic force from being applied to the capsule in the human body, thus avoiding pain and prospective damages.

Iddan disclosed an invention describing an endoscopic capsule with active propulsion [28]. The device includes a motor consisting of an electromagnetic stator unit and a permanently magnetized rotor unit. The rotor unit may consist of blades attached to a rotatable axle Fig. (**10**).

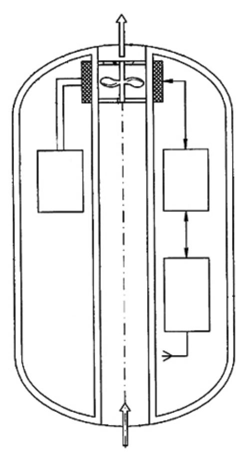

Fig. (10). Representation of the capsule described by the invention of Iddan.

The rotor may be lodged in a duct inside the capsule's body. The blades may be wholly or partially made from a permanently magnetized material such as neodymium-iron boron alloy. In this configuration, the blades together form a magnet such that one of the blades is the north pole of the magnet and the other opposite blade is the south pole of the magnet. An energy receiving unit in the device may include a coil configured to receive electromagnetic energy and an element, coupled to the coil, configured for converting the received electromagnetic energy to energy for powering the components of the device. The energy receiving unit may further be configured for storing the voltage, such as by including a capacitor or chargeable battery. The power source may receive power from external ultrasonic power sources, or electromagnetic wave sources, or magnetic sources. The device may be modified to include more than one duct. More specifically, each of the secondary ducts may have a plurality of openings through which fluid may be ejected to provide a propulsive force. The use of multiple fluid jets having different orientations and velocity may be used to propel the device in various different directions.

Dario *et al.* proposed an invention concerning a robotic endoscopic capsule equipped with an active locomotion system [29]. The patent describes a device for endoscopic use capable of autonomous movement and power supply within a body cavity, with the possibility to control its movement from outside the patient's body in order to accomplish medical, diagnostic and therapeutic procedures. In particular the active locomotion is obtained by means of a set of legs in superelastic shape memory alloy, a material largely used in the biomedical industry (Fig. **11**).

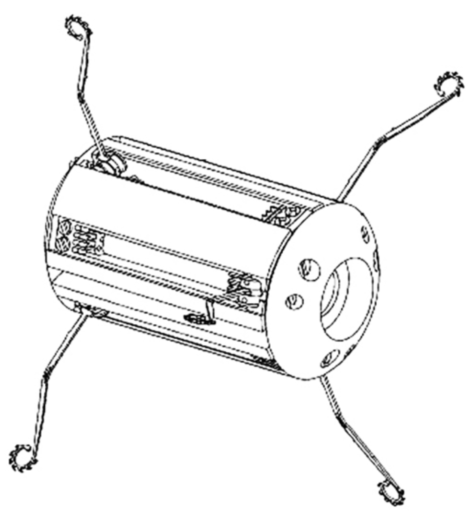

Fig. (11). Representation of the robotic capsule described by the invention of Dario.

Each leg is lodged inside an axial groove on the lateral surface of the cylindrical body of the pill and has two DOF: one active DOF to allow rotation of the whole leg around a pivot point in order that each leg can open and close radially; one passive DOF to bend the leg around an intermediate portion for adapting it to the deformability of the tissue of the GI tract. In this way, legs can provide the pill with active locomotion in the small intestine and colon for matching different diameters. The endoscopic capsule includes also an energy source and a microcontroller to actuate the legs, a camera to acquire images, a transceiver for receiving the commands teletransmitted by the operator and for transmitting the images acquired by the camera.

RECENT PATENTS ON INSPECTION INSIDE THE COLON

Horn disclosed a system for the screening of colorectal polyps by means of an endoscopic pill [30]. A polyp detector may be included as a feature of a processor inside the workstation and may select from an image sequence one or more pictures that may be associated to polyp identification. As an example, the polyp detector may be an algorithm that may be implemented to detect in one or more image frames the presence of predetermined features and/or parameters. The output may be transferred to a display connected to the workstation. In particular, the selection of image frames is based on automatic detection of one or more geometric shapes that may be polyp structures in an image frames.

Shinichi presented an invention about WCE for colon [31]. According to this invention, the capsule has an image capture controller with a "power saving mode", in which the capturing rate of the CCD image sensor is 2 frames/sec, and a "normal capture mode" with a rate of 30 frames/sec. The external receiver is placed at a position where the antenna of the capsule can receive the image capture initiation signal from an external transmitter when the device reaches the region to be inspected, in this case the colon. Therefore the receiver is placed at right lower abdominal quadrant of the patient's body. When the pill is close to the entrance of the large intestine, the device enters the area of the radio waves of the image capture initiation signal from the external transmitter and the image capture signal initiation is received by the antenna. The capsule integrates also a timer circuit and a pressure sensor. The former is activated after the capsule is swallowed and counts the elapsed time until it is in the small intestine. During this period the control circuit maintains the power saving mode. The latter is a piezoelectric sensor measuring the intensity of the pressure applied to the capsule from outside, i.e. the GI wall. As pressure is higher in the small intestine than in the colon, when the pressure applied to the capsule becomes low, the control circuit determines that the capsule endoscope reaches the large intestine and switches from the power saving mode to the normal capture mode.

Mintchev *et al*. proposed a method for the inspection of the colon by an endoscopic capsule [32]. The capsule is covered by a shell which dissolves naturally once it enters the large intestine, allowing dilatation of expandable components attached to each end of the capsule, thus avoiding tumbling of the pill while it passes through the colon. Once the shell starts dissolving, the image sensor along with the illumination system turns on. The outer shell may be fabricated from a colon-targeting material that would be stable in the stomach and small intestine, but would dissolve in the colon. In particular crosslinked polysaccharides are stable in the small intestine since they are not attacked by amyIases found in the small intestine, while they are suitable for colon-targeting due to their enzymatic degradability by the microflora of the large intestine. Conversely, using pH alone to select an organ would be insufficient to target the colon as opposed to the small intestine, since there is only a small difference in pH values between the small and the large intestine. Self expansion of the components at the ends of the capsule may be achieved by diffusion of water molecules by osmosis or release of potential energy as in the case of springs.

RECENT PATENTS ON BIOPSY, ULTRASOUND AND OTHER FEATURES

A method to obtain tissue sampling was disclosed by Swain [33]. The endoscopic system consists of a plurality of, at least two, connected capsules: one with an images acquisition unit and a transmitter and the other with a sampling mechanism (Fig. **12**).

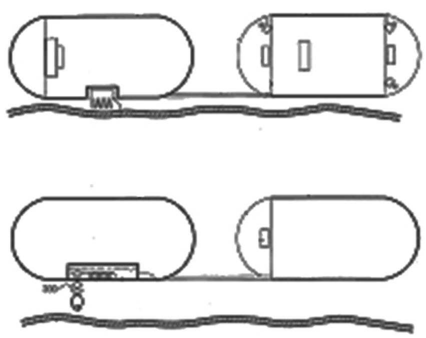

Fig. (12). Representation of the capsule for biopsy described by the invention of Swain.

The devices may be connected by a thread, tube, cable, wire or flexible narrow shaft. Even so, the connecting wire ensures physically and/or electrically connection between the two pills. One device may capture and transmit images of the other device, e.g. images of samples or images of samples reacting with a substance. One device may capture an image of some portion or all of the other device, and perhaps a portion of the GI tract surrounding the device. A capsule may have an image sensor at each end to capture an image of an endo-luminal area with the frontal one and an image of the second pill with the back one. One of the devices may for example be fitted with an instrument or set of tools or biopsy mechanism to take a biopsy of endo-luminal tissue, cells or liquid and the other device may for example have an imager and control features to view or direct the biopsy procedure. The view of an imager may optimally include a biopsy mechanism when it is extended, for example, to grasp a tissue. Such a view might let an operator view, supervise and manoeuvre a biopsy mechanism in real-time, and select the location and position for activating the biopsy mechanism. This invention depicts several possible solutions of mechanisms enabling biopsy. As an example one of the two capsules may be fitted with an articulated arm which may extend from the device to grasp and collect a piece of tissue. The arm and the endo-luminal area to be grasped may be viewed by an imager in the other device so that the biopsy process may be monitored, for example, on an external workstation or other display. The extracted tissue may be withdrawn with the articulated arm back into a storage compartment in the device where the tissue may be stored until the device is retrieved. A biopsy sample may be stored in a compartment inside a device, and the arm or grasping instrument may be used to retrieve another sample of tissue. A curved flat spring that may be released when the arm is retracted may be used to loose a sample tissue from the arm or biopsy instrument and store the sample in a space or compartment within the device. The curved flat spring may be moved out of the way once the arm was re-extended to grasp another sample. The compartment may include a liquid, which may be a preservative, saline or a fixation liquid, such that the tissue is kept in a preserving environment.

Miyake proposed a capsule ultrasonic endoscope [34]. Besides all features for image acquisition, transmission and power supply, the body of the capsule contains an ultrasonic transducer and a medical solution working as an ultrasound transmitting medium to transmit ultrasonic oscillations generated by the ultrasonic transducer, an electromagnet which constitutes a medical solution releasing means to release the ultrasound transmitting medium and an abutting piece which is provided on a transducer cover and is made of a magnetic body, for example a metal (Fig. **13**).

Taniguchi disclosed an invention of capsule with an ultrasonic module [35]. In this device an ultrasonic transducer unit, which is a unit to be rotated, and a drive unit for rotating the ultrasonic transducer unit freely back and forth, are enclosed in a capsule sheath serving as a casing (Fig. **14**).

The configuration of the conventional capsule-type ultrasonic endoscope is such that the ultrasonic transducer

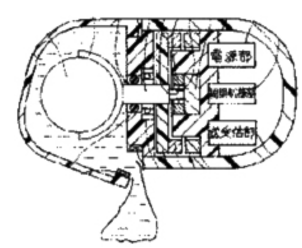

Fig. (13). Representation of the invention of Miyake.

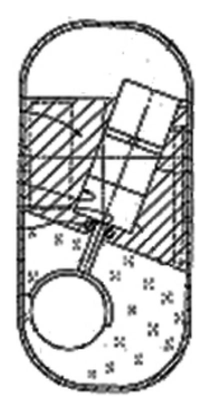

Fig. (14). Representation of the capsule with ultrasonic module described by the invention of Taniguchi.

unit transmits and receives ultrasonic pulses, for example, in the radial direction perpendicular to the longitudinal central axis of the capsule sheath, when the ultrasonic transducer unit is rotated by the drive unit. An ultrasonic transfer medium such as fluid paraffin, water, and aqueous solution of carboxymethyl cellulose is sealed in the inner space of the capsule body.

Ito *et al.* proposed an endoscopic capsule system with a wearable jacket having the communication functions of an antenna [36]. The jacket is provided with circuitry to obtain various data of a patient by radio without using lead wires, cables or copper patterns. The obtainable data may include body functions (e.g., pulse, blood pressure, temperature and pH) of the patient and images of GI tract. The antenna jacket is configured to be flexible and durable, light weight, with a high density of antenna arrangement, and acquisition of image signals with a high signal to noise (S/N) ratio. The antenna jacket employs a 2D-DST (two-dimensional diffusive signal transmission) technology. According to the 2D-DST technology, a 2D-DST substrate is configured such that a plurality of chips (communication modules) are distributed between two signal layers so that adjacent chips are locally and electrically connected with each other (Fig. (**15**)).

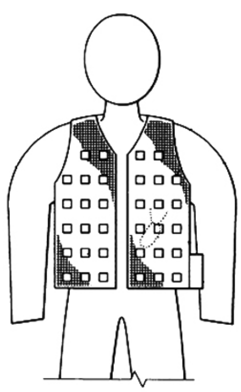

Fig. (15). Representation of the invention of Ito.

Then, data are relayed across the plurality of chips from an origin to a destination by packets. According to the embodiment, the antenna jacket, which is the 2D-DST substrate in this case, is provided with two conductive sheets and insulating sheets in order to insulate the two conductive sheets from outside. The communication modules constitute a circuitry for obtaining the image signal transmitted by the capsule, a circuitry to transmit electromagnetic waves for supplying electrical power and for transmitting control signals, and a circuitry to obtain body functions of the patient. The antenna jacket has also a control unit for the management of the entire operations of the circuitries of the antenna jacket. Furthermore, the communication modules are divided into two types, which include image modules to obtain image signal transmitted from the capsule and to transmit radio waves to supply power and to transmit control signals, and measurement communication modules to measure body functions and obtaining measurement results.

Frisch *et al.* disclosed a system for downloading and processing services for a plurality of satellite sites that may perform WCE [37]. Downloading and reviewing the acquired data may be time consuming and require purchasing of dedicated and expensive equipment and software. In addition, successful diagnosis is based on special training of health professional. The aim of this invention is to make WCE more cost effective and accessible in remote rural areas with long travel distances and in places where population may be scattered by performing data acquisition of WCE at satellite sites in proximity to the patient, while either all or some of the downloading, processing, reading and/or interpretation of the procedure may be carried out in a central site. This may be equipped with a data downloading unit and a data processing unit besides a data storage unit. This may be transferred from a satellite site to the central one by wireless transmission, mail or hand delivery. The processing unit may be a workstation with dedicated software. An interface may be used to download data from the storage unit to the processing one. After the download, data may be further processed. One or more algorithms may be implemented to decipher pathological conditions of interest. A health professional may review data and prepare a report based on findings. Down-loaded data may be sent back to satellite site for review and possibly further analysis.

CURRENT & FUTURE DEVELOPMENTS

It is clear from the first part of this manuscript that WCE is a novel procedure and at present its merit is limited to the visualisation of the mucosa of the GI tract. Most research groups, both universities and private companies, have recently filed several patents, the most significant reported in this review. The inventions described may lead to capsules with new capabilities. Therefore the next generation of WCE may lead to pills able to perform tissue sampling, e.g. via optical biopsy; to measure temperature, pH and pressure within the GI tract; to vary the frame rate to save energy in order to look inside as many portions of the GI tract as possible; to enable accurate localisation of the pill within the GI tract; and to propel independently of peristalsis, thanks to magnetic actuation, electrical stimulation, or other solutions based on robotics.

On the other hand, major areas of future research include: 1) the development of image sensors with better resolution than current capsules for the detection of pathologies at an earlier stage, which are not detectable at present; 2) image transfer and processing in real-time [38]; 3) new miniaturised actuators in order to realize robotic capsules; 4) sensors for therapeutic tasks, such as drug delivery; 5) miniaturised power sources with high efficiency in order to supply energy to all components.

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