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Wireless Capsule Endoscopy (WCE)

Review

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Abstract – Wireless capsule endoscopy is presently taken into consideration the gold standard investigation of the small bowel. It is both realistic for physicians and easily accepted by patients. Prior to its improvement, forms of imaging investigations of the small bowel were available: radiologic and endoscopic. The first class is much less invasive and comfortable for patients; it offers the ensemble of the small bowel; however, it could suggest radiation exposure. Images are built primarily based totally on signals emitted through diverse equipment and require unique interpretation. Endoscopic techniques offer real time coloured images obtained through miniature cameras from within the small bowel, require interpretation only from a clinical point of view, can also additionally permit the opportunity to carry out biopsies, however the investigation only covers part of the small bowel and are greater hard to just accept by patients. Wireless capsule endoscopy is the present-day answer that overcomes part of the preceding drawbacks: it covers the complete small bowel, it presents real time images obtained through cameras, it's painless for patients, and it represents a plentiful source of information's for physicians. Yet, it lacks motion control and the opportunity to carry out biopsies or administer drugs. However, sizable effort has been orientated in these directions through technical and medical teams, and more advanced capsules will actually be available the following years.

Keywords – Medical robots, Digestive endoscopy, Robotic endoscopic capsules, Wireless capsule endoscopy (WCE), Microsystem, Technologies

I. INTRODUCTION

For many years, the small bowel has been a hidden a part of the human body, and not using an opportunity to investigate it till 1895, while the first X-ray was invented (1). Only then, physicians had the risk to glimpse at this organ and to begin imagining the possibilities that this discovery brought about. The first steps in clinical imaging have been faint and presented only a few data with clinical meaning. But nevertheless, they represented the start of a technique that turned into constantly advanced with new devices, techniques, processing activities and modern ways approaches to interpret the acquired images.

1. Brief records of small bowel investigations

The first imaging system used for the investigation of the small bowel turned into the X-ray. In classical abdominal X-rays, the small bowel is placed centrally in the image, and the colon frames it peripherally. The mucosal folds are seen throughout the complete width of the small bowel, however the image best turned into pretty poor, superimposition of various structures turned into and nevertheless is inevitable, accordingly the related pathology turned into difficult to perceive and diagnose. A sizable contribution withinside the visibility of diverse characteristics of the small bowel in an X-ray was represented through a previous ingestion of a contrast agent, which emphasised the aspect of particular areas in the obtained images. Initially, bismuth preparations have been used for those purposes, at the end of XIXth century, however in 1910, Krause, Bachem and Gunther from Bonn Polyclinic advocated barium sulphate as alternative on account that bismuth turned into taken into consideration too toxic

[1]. Barium has very critical properties: it is adherent to the small intestinal wall (contour, shape, wall lining and length are more seen), and it absorbs X-rays, consequently the initial rays are strongly attenuated and the influence they depart at the receptor, for that particular area, may be very near white (similar to the imaging aspect while the ray is absolutely attenuated). The small bowel turned into more visible on the new X-rays, in nearly white shades. As the medical world developed, so did the imaging investigation techniques. The utilization of contrasted agents turned into exploited even more; later on, double contrast small bowel investigation commenced to be used. The improvement of CT technology in 1989 led to new route concerning imaging investigations, so in the early 1990's CT enterography added new views at the small bowel. Other radiology techniques without radiation exposure have been additionally used: magnetic resonance imaging, magnetic resonance enteroclysis and enterography, ultrasound or contrast enhanced ultrasound [2].

These techniques are much less invasive and higher familiar by patients; however, they lack the opportunity to carry out biopsies. This disadvantage was solved through the endoscopic techniques: push enteroscopy, ileocolonoscopy, intraoperative enteroscopy, that are invasive and not comfortable for patients; nevertheless, from an imaging point of view, they provide real time images of the small bowel, obtained with miniature cameras, not images reconstructed through various techniques, which includes radiology investigations [3]. All those investigations have advantages and disadvantages and provide complementary data on the small bowel. But what turned into lacking is an investigation that could permit an entire and accurate visualization of the small bowel.

2. key aspects

Technology needs to assist in further promoting CRC (Colorectal cancer) screening and permit, as a consequence, a tailored and much less invasive treatment. However, the aforementioned elements restrict the popularity of conventional colonoscopy-based screening protocols. For these reasons, extraordinary techniques had been proposed, which includes the combination with faecal occult blood test (FOBT), with a view to lessen the number of colonoscopies. Nevertheless, this method is burdened through an excessive rate of false negative results [4]. Another alternative is based totally computed tomography (CT) of the colon; but it calls for ideal bowel preparation and substantial X-ray exposure [4]. Direct visualisation of the colonic mucosa is preferred with a view to locate diffused mucosal alterations, as in inflammatory bowel diseases, in addition to any flat or sessile colonic lesions. Nevertheless, standard colon WCE suggests inadequate sensitivity in detecting colonic lesions even after a major technology upgrade [5]; furthermore, the intense bowel preparation required, collectively with the fact that it isn't always feasible to carry out a biopsy, deprives colon WCE from getting the lead in the field [6].

A best diagnostic tool for the colon needs to offer direct visualisation and pain-free navigation via a sufficiently distended colon. This may be performed through avoiding pressure at the bowel wall while advancing in addition to avoid massive out of control painful distension of the colon and/or loop formation. Regarding lesion visualization, the medical device need to be dependable in detecting lesions at least >5 mm, that are characterised by the potential for dysplasia, and this of course includes the areas behind the bowel folds, that are regularly unexplored with traditional endoscopy, despite the wide angle of vision, and/or using transparent caps [8].

3. Industrial solutions

Wolf and Schindler are the fathers of GI endoscopy. They invented the inspection of the GI tract with semi-flexible endoscopes in 1868. Nowadays, flexible scopes are taken into consideration the mainstream endoscopic tools; they permit reliable diagnoses in the GI tract displaying additionally healing and surgical capabilities. However, considering the fact that scopes are nonetheless alternatively inflexible instruments, there are excessive probabilities of traumatic approaches, additionally because of the manoeuvring mechanism, which limits patients' tolerability and acceptance of the diagnostic technique. Moreover, pain or sedation-associated troubles restrict the pervasiveness of a mass-screening campaign, that's a high public health priority, making patients reluctant to undergo endoscopy. Only mass screening ensures the suitable choice of who need to go through endoscopy to make certain early detection and treatment of asymptomatic pathologies, with specific interest to CRC. As said, diagnosis and treatment in the GI tract are ruled by means of using flexible endoscopes. A few large companies, particularly Olympus Medical Systems Co. (Tokyo, Japan), Pentax Medical Co. (Montvale, NJ, USA), Karl Storz GmbH & Co. KG (Tuttlingen, Germany), and Fujinon, Inc. (Wayne, NJ, USA) cover the plurality of the market in flexible GI endoscopy. With admire to new technology, this discipline is unexpectedly rising, as flexible endoscopes are taken into consideration a platform for superior diagnostic and therapeutic approaches. In current years, new imaging modalities aiming to enhance traditional white light endoscopy had been adopted in clinical routine and are continuously being in additional advancement. The maximum prominent imaging enhancement technology are narrow band imaging (NBI) by means of Olympus, Scan by means of Pentax, flexible spectral imaging colour enhancement (FICE) by means of Fujinon, autofluorescence imaging (AFI) by means of Olympus, and confocal laser endomicroscopy (CLE) by means of Pentax. Literature indicates that enhanced imaging modalities will have an added value in the diagnosis of various pathologic entities with positive consequences on accuracy, sensitivity and specificity and the cost of procedure [8– 12].

The field of interventional endoscopy is likewise continuously evolving. Recent developments, which include over-the-scope clips (OTSC®), allow endoscopists to carry out extra complicated and radical techniques, or even spare patients from surgical procedure via a much less demanding endoscopic intervention [13]. The FTRD® device through Ovesco Endoscopy AG (Tübingen, Germany) permits endoscopic full-thickness resection in the colorectum in an effective manner [14] Such novel techniques increase the sector of utility of endoscopic devices properly into the surgical domain. OTSC® [13]; and FTRD® device through Ovesco Endoscopy AG [14] (Courtesy of Ovesco Endoscopy AG, Tübingen, Germany) The FDA approval of the first WCE has brought about a novel diagnostic generation in endoscopy, particularly for small bowel diagnosis. Furthermore, different indicators encompass surveillance of small intestinal polyposis syndromes or tumours in addition to evaluation of reaction and/or medical headaches of celiac disease [15, 16]. Moreover, two-headed tablets similarly goal the oesophagus and the colon for CRC screening. Latest developments which have been delivered into the marketplace are basically upgrades of preceding WCE devices, each in terms of technology (e.g., better resolution, longer battery lifetime) and/or utility (e.g., movement-sensitive control of frame acquisition frequency, modifications of capsule size to promote sensitivity in colon screening). However, novel technology needs to mix the low invasiveness and high patient comfort of wireless endoscopic devices with novel, extra effective technological functions which will deal with big upgrades in CRC diagnosis and treatment [17].

4. Robotic capsule

A robotic capsule platform includes at least six primary modules: i) locomotion, ii) localization, iii) vision, iv) telemetry v) powering, and vi) diagnosis and treatment tools. However, most robot endoscopic capsules, advanced to date, encompass only a subset of the aforementioned modules because of size constraints. Technological integration is challenging, however, thanks to contemporary-day progresses in microsystem technology and micromachining, in addition to in interface and integration, contemporary-modern devices can embed most of those modules and offer both diagnostic and treatment functionalities. (Courtesy of Virgilio Mattoli)

4.1. Locomotion

Locomotion is an essential issue that ought to be taken into consideration whilst designing a robotic endoscopic capsule. WCEs may be active or passive, relying on whether or not they have got controlled or non-controlled locomotion. Passive locomotion presently dominates the market (e.g., PillCam® WCEs). Active locomotion continues to be in most cases at studies level, however it has super potential, considering the fact that it might permit the clinician to manoeuvre the tool for particular target. However, the principle trouble is associated with technological integration. It is tough to embed a locomotion module right into a swallowable capsule due to the size of actuation and power constraints. For instance, the power consumption of a legged capsule device is set 400 mW only for motors, therefore requiring the combination of an excessive capacitance and additionally bulky battery [18]. Two essential techniques permit the implementation of active locomotion in an endoscopic swallowable capsule: one is composed in embedding on-board a miniaturized locomotion system(s), i.e. internal locomotion; the other requires an external method, i.e. external locomotion. This latter method generally relies on magnetic field sources.

4.1.1. Internal locomotion

An exciting active capsule system for gastroscopy was developed by means of Tortora et al. [19]The submarine-like robot capsule exploits four independent propellers actuated by means of DC brushed motors; positioned withinside the rear part of the capsule, propellers are wirelessly managed to assure 3D navigation of the capsule in a water-filled stomach. A superior model of this capsule, which embeds a digital digicam module, has been advanced by means of De Falco et al. [20]. Other feasible bio-stimulated tactics of swimming in a water-filled stomach cavity encompass flagellar or flap-based swimming mechanisms [21, 22]. Caprara et al. currently advanced a revolutionary method for stomach inspection that includes a soft-tethered gastroscopic capsule; the digital cam capsule is orientated by water jets supplied by means of a multichannel outside water distribution system [23].

Internal locomotion platforms: a Swimming capsule by means of Tortora et al. [19] and by means of: a. De Falco et al. [20]; b. water jet-based soft-tethered capsule by means of Caprara et al. [23]; c. earthworm-like locomotion tool by means of Kim et al. [24, 25]; and d. wired colonoscopic capsule with micro-patterned treads by means of Sliker et al. [28] Several mechanisms based on internal locomotion approaches had been advanced for targeting the whole intestine (i.e., large and small bowel). A mechanism, that's bio-stimulated by means of an earthworm-like locomotion method, turned into advanced by means of Kim et al. [24, 25]; it includes cyclic compression/extension shape-memory alloy (SMA) spring actuators and anchoring structures based on directional micro-needles.

Another bio-stimulated solution for inner locomotion turned into proposed by means of Li et al. [26]. It exploits a mechanism mimicking cilia extension the use of six SMA actuated units, every supplied with two SMA actuators for allowing bidirectional motion. A paddling-based totally technique, for crawling in the intestine, turned into proposed by means of Park et al. [27]. The capsule makes use of more than one legs that tour from the front to the back of the capsule, in touch with the tissue, permitting directional propulsion alongside the lumen. Sliker et al. advanced a wired colonoscopic capsule composed of micro-patterned treads [28]. The capsule drives eight polymer treads concurrently via one single motor. Interaction of the treads (positioned at the outer surface of the capsule) with the tissue ensures propulsion of the capsule device. Bio-inspired leg-based capsules have been additionally advanced by means of The Bio Robotics Institute of the Scuola Superior Sant'Anna in Italy. Increasingly state-of-the-art legged robotic prototypes the use of embedded brushless motors (i.e., 4 legs [18], 8 legs [29], and 12 legs [30, 31]), have been advanced beginning from a first generation SMA-based solution [32].

Legged capsules established powerful bidirectional control, stable anchorage and adequate visualization of the lumen without the need for insufflation. Finally, electric stimulation of the GI muscle tissues turned into a propose as a way for more or less controlling capsule locomotion or at least to prevent it by means of producing a temporary restrict in the bowel [33, 34]. Although internal locomotion has a significant advantages, such as local distension of the tissue (i.e., no insufflation is needed for accurate visualization of the lumen), it comes with a dramatic drawback: the excessive inner encumbrance had to gain the size of an ingestible capsule (e.g., because of the presence of actuators, transmission mechanisms and high-capacity power modules).

4.1.2. External locomotion

The outside locomotion technique makes use of permeant magnets or electromagnets and includes external field sources that interact with inner magnetic components, which are embedded in the capsule, to offer navigation and steering. The advantage of the outside technique is that there are not any on-board actuators, mechanisms and batteries, thanks to a small-integrated magnetic field source, i.e. in most cases an everlasting magnet. Given Imaging Ltd. investigated the usage of a hand held external everlasting magnetic source to navigate a capsule in the upper GI tract using of a custom designed model of PillCam Colon, which integrates an everlasting magnet, as a part of the European FP6 assignment called "Nano based Capsule-Endoscopy with Molecular Imaging and Optical Biopsy (NEMO assignment)" [35].

Carpi et al. invented a cardiovascular magnetic navigation system (St. Louis, MO, Niobe, Stereotaxis, USA) for the robotic navigation of a magnetically modified endoscopic capsule, i.e. a PillCam SB, Given Imaging Ltd., for gastric exam [36, 37]. External locomotion platforms: a GI tract exploration platform advanced through Carpi et al. exploiting the Stereotaxis gadget [36, 37]; magnetically-pushed capsule with vibration by Ciuti et al. [43]; gastric examination platform advanced cooperatively through Olympus Inc. and Siemens AG Healthcare [46]; and d SUPCAM endoscopic capsule (Lucarini G, Ciuti G, Mura M, Rizzo R, Menciassi A. [59] An energetic locomotion technique primarily based totally on everlasting magnets (outside and inside the capsule) changed into proposed through Ciuti et al. [38, 39]. The platform combines the benefits of magnetic field strength and restrained encumbrance with accurate and reliable manipulate through the usage of an anthropomorphic robot arm. Tested in a comparative study, colonoscopy the usage of this novel robotically driven capsule changed into feasible and showed adequate accuracy as compared to conventional colonoscopy [40]. This technique changed into investigated in the framework of the FP6 European Project called "Versatile Endoscopic Capsule for GI Tumour Recognition and therapy (VECTOR project)" [41]. A significant derivative technology from the VECTOR project consisted of a soft-tethered magnetically-driven capsule for colonoscopy [42]; the device represents a trade-off capsule and conventional colonoscopy combining the benefits of low-invasive propulsion (through "front-wheel" locomotion) with the multifunctional defined for treatment.

Ciuti et al. additionally proposed a magnetically driven capsule with embedded vibration mechanisms (i.e., motor with asymmetric mass on the rotor) which permit progression of the capsule alongside the lumen and decreased friction [43]. Mahoney and Abbott addressed an everlasting magnetic-based actuation approach for helical capsules through optimizing magnetic torque whilst minimizing magnetic attraction [44]. The same authors proven the 5-DOF manipulation of an untethered magnetic tool in fluid [45]. A novel endoscopy platform for gastric examination changed into advanced through Olympus Inc. and Siemens AG Healthcare (Erlangen, Germany). The system combines an Olympus endoscopic capsule (31 mm in period and 11 mm in diameter with two 4 frames per second (fps) image sensors) and a Siemens magnetic guidance device, composed of magnetic resonance imaging and computer tomography. A dedicated control interface lets the navigation of the capsule system with 5 degrees of freedom (i.e., 3-D translation, tilting and rotation) [46]. A hand-guided electromagnetic system is at the basis of the robot endoscopic platform advanced throughout the European FP7 project called "New cost–effective and minimally invasive endoscopic device able to investigate the colonic mucosa, making sure an excessive degree of navigation accuracy and more desirable diagnostic capabilities (SUPCAM project)" [47, 48]. The external electromagnetic supply navigates a colonoscopic round-form capsule supplied with an inner everlasting magnet, capable of carry out a 360° inspection through internal digital rotation. A significant limitation of the external magnetic locomotion technique is the problem in acquiring effective visualization and locomotion in a collapsed environment. Solutions for local tissue distension were proposed by several researchers [49, 50].

4.2. Localization

Capsule position and orientation are vital to discover the lesions in the GI tract, determine the follow-up treatment and offer a feedback for capsule motion (in the case of active locomotion). For this reason, an accurate localization system is essential for WCE [51]. Commercially available WCEs appoint distinctive localization techniques, e.g. Given Imaging patented a localization approach in 2013 based on a single electromagnetic sensor coil [52], as an alternative Intromedic's localization approach is based on electric potential values [53]. One of the strategies used for localization includes taking images from the capsule: every region of the GI tract is diagnosed through anatomical landmarks [54]. Spyrou et al. proposed an image- based tracking approach the usage of algorithms for 3-D reconstruction based on the registration of consecutive frames [55].

Several studies groups have as an alternative localization strategies based on magnetic fields and electromagnetic waves. Low-frequency magnetic signals can pass through human tissue without attenuation [56], plus, magnetic sensors do now no longer need to be in the line of sight to detect the capsule [57]. However, precision decreases if a ferromagnetic tool is by accident inserted into the workspace [58]; additionally, the size of the everlasting magnet is constrained through the dimensions of the capsule, which additionally limits the accuracy of results [59]. Moreover, if a magnetic actuation approach is implemented, it's far feasible that an undesired interference with the magnetic localization system might also additionally occur. Weitschies et al. have been the first to equip a capsule with an everlasting magnet for passive capsule endoscopy [60, 61]. A 37-channel superconducting quantum interference device (SQUID) magnetometer was used to report the magnetic field distribution over the abdomen, for several time intervals. The resolution of the position changed into few millimetres and the temporal resolution was in the order of milliseconds.

Wu et al. [62] advanced a wearable monitoring vest which include an array of Hall-Effect sensors. This was used to track a capsule supplied with a Neodymium magnet. The array changed into round 40 cm × 25 cm × 40 cm (period × width × height) to be able to cover the stomach and small intestinal area of a normal human body. Instead, Plotkin et al. [63] used a large array of coplanar transmitting coils (8x8 matrix). At the start of the procedure, a complete transmitting array is sequentially activated to gain the initial position of the receiving coil, that's enclosed inside the capsule. Only a subarray of 8 coils is used in the following tracking stages. The authors document a 1-mm, 0.6° tracking accuracy. Another technique changed into proposed through Guo et al. [64] who used 3 external energized coils fixed on the patient's abdomen. The coils have been organized to excite 3-axes magneto-resistive sensors inside a capsule that measured the electromagnetic field strength. This approach is based totally at the precept of magnetic dipole. The position and orientation mistakes reported 6.25–36. sixty-eight mm and 1.2–8.1°in the range of 0–0.4 m.

Several approaches are feasible for the utility of active actuation systems. The Olympus company [65] proposed a plurality of magnetic field detecting devices. They have been located on the patient's body to detect the strength of the magnetic field in the coil of the capsule and have been triggered through an external magnetic field device. The operating frequency lies in the range of 1kHz to 1MHz to keep away from absorption of the living tissue. This technique has an accuracy of under 1 mm whilst the resonant circuit is located inside 120 mm from the detecting coil array. Similar ideas have been proposed through Kim et al.

[66], using magnets inside an endoscopic capsule. An external rotating magnetic field forcing the capsule to rotate. Three hall-effect sensors inside the capsule have been employed to measure the position and the orientation of the capsule. The authors state that the largest position detection error is much less than 15 mm, and the maximum orientation detection withinside the pitching direction is within −4° and 15°.

Salerno et al. proposed a localization system, well matched with external magnetic locomotion, based totally on a triangulation algorithm. It uses an on–board tri–axial magnetic sensor to detect the capsule in the GI tract. Position errors suggested are of 14 mm along the X axis, 11 mm along the Y axis (wherein X and Y are in the plane of the abdomen) and 19 mm along the Z axis.

Salerno et al. [67] additionally advanced online localization system (working at 20 Hz) embedding a 3-D Hall sensor and a 3-D accelerometer with pre-calculated magnetic field maps describing the external-supply magnetic field. The authors suggested a position errors of less than 10 mm when the localization module and the external magnet are at a distance of 120 mm. The localization algorithm supplied Di Natali et al. [41, 68] is well matched with magnetic manipulation. It is a real-time detection approach using multiple sensors with a pre-calculated magnetic field map. The proposed technique confirmed a position detection error 5 mm, and angular error below 19° within a spherical workspace of 15 cm in radius. The same authors proposed a Jacobian-based iterative approach for magnetic localization in robotic capsule endoscopy. Overall refresh rate changed into 7 ms, as a consequence allowing closed-loop control techniques for magnetic manipulation running for faster than 100 Hz. The average localization error expressed in cylindrical coordinates was below 7 mm in each the radial and axial components and 5° in the azimuthal component [69].

Electromagnetic wave methods also are used along these approaches. Radio frequency has been broadly used for locating an object in both outdoor and indoor environments attaining an accuracy of hundreds of millimetres [70]. Given Imaging Inc. integrated this method of localization in the PillCam®SB system. Eight sensors located in the upper abdomen receive of the strength of signals emitted by the capsule. The average position error is about 37.7 mm and the maximum error is 114 mm [71]. Medical practices propose other procedures which can be currently used in the clinical procedure. Among those procedures is the utility of medical imaging. X-rays also can be exploited to track an object, e.g. an endoscopic capsule located inside the digestive tract [36]. The gamma scintigraphy method is used as properly to visualise the placement of the Enterion capsule, a drug-delivery-type capsule, in real time [72]. The MRI system changed into proposed through Dumoulin et al. to track interventional equipment's in real time [73].

4.3. Vision

The foremost purpose of a CE is of direction to reap photos of the internal anatomy. Therefore, imaging skills, in phrases of modality, sensor characteristics and illumination, are among the maximal crucial functions that should be taken into consideration while designing those structures [74, 75]. A variety of solutions were proposed providing quite a range of capabilities. They may be taken into consideration on this section: i) sensor resolution, ii) sensor location, iii) field-of-view (FoV), iv) illumination, and v) modality.

5. Sensor temporal and spatial resolution

Both temporal frames in second (fps) and spatial number of pixels are crucial resolution standards for imaging. Temporal resolution determines the information that the capsule can cover whilst traveling via the patient. If that is too low, there's a risk of omitting gastrointestinal regions from the examination. Typical commercial systems initially operated at 2–3 fps only a few years ago [76], however, faster systems above 16 fps are the more recent standard [77], frequently with variable fps manage settings. Spatial resolution determines the quality of diagnosis that may be accomplished for site analysis. This may be especially crucial if the texture or appearance of the gastrointestinal surface is used for diagnosis or staging of the disease. This functionality might be especially crucial for pathologies such as Barret's oesophagus wherein picture texture is an indicator of disease progression. The typical spatial resolution for early capsule platforms turned into about 360 × 240 pixels, however, new systems are capable to obtain better resolutions [77, 78].

6. Sensor location

The position of the sensor and lens determines the region imaged with the aid of using the traveling capsule. Since most devices are designed with an expected travel direction in the long axis of the capsule, the majority of image sensors are set up on the tip of the capsule. More lately, capsule integrating more than one camera were evolved and might doubtlessly collect photos searching ahead and backwards, consisting of PillCam® Colon 2 and UGI capsules. Similar outcomes will also be accomplished via lens design [79]. In particular, micro lens arrays or lenticular lens arrays, that have been confirmed in laparoscopic surgery [80], might be used to provide a multi-view image using of a single sensor to keep a small device footprint. Different configurations, where a side viewing sensor is used, have additionally been explored due to the fact searching forwards isn't always continually the clinically most suitable configuration [81]. Side viewing capabilities can doubtlessly map the whole surrounding lumen around the capsule and make certain a continuous monitoring capability, which also can be crucial for mapping algorithms.

7. Field-of-view

The confined workspace within the gastrointestinal system method that the distance between the capsule and the tissue could be very small. This calls for capsules to offer a wide field of view so one can look at a sufficient image of the tissue walls. Typically, the FoV of capsules ranges between 140° and 170°. However, one-of-a-kind setups were explored, for instance the CapsoCam capsule provides a new concept with a 360° panoramic lateral view with 4 cameras [81].

8. Illumination

Image quality is inherently ruled with the aid of using the illumination and sensor capabilities of the endoscopic capsule. Illumination is usually provided with the aid of using LED sources configured to provide white images, which are usually used for interpretation by the physician. Adaptive illumination techniques have lately been under investigation for attaining most suitable image quality whilst maintaining battery power based on picture processing [82]. Different techniques may be employed to preserve power, e.g. the brightness of the image may be used to estimate the distance from the surface under observation due to the fact illumination power is a function of distance. The overall image brightness can then be adapted to keep diagnostic image quality.

9. Modality

White mild (WL) is the principle modality for WCE imaging due to the fact it's far the most properly understood signal for interpretation by the physicians. Nevertheless, molecular imaging has been explored with the aid of using some of teams and projects [83]. Autofluorescence capsule prototypes were explored [84] for potentially detecting disease without an on-board digicam [85, 86]. NBI doubtlessly exposes useful subsurface vessel information which could characterize disease [87].

The type of light and the 2D or 3-D image modalities of the capsule have additionally been explored. It is feasible that multiple 2D images can doubtlessly provide a 3-D reconstruction of the video, that could permit more accurate lesion classification [88–91]. Stereoscopic systems have already been evolved, consisting of the one evolved in 2013 with the aid of using Simi et al. for laparoscopic procedures [92]. A new concept of capsule with a stereo digicam system for colonoscopy may be investigated with the aid of using the authors within the EndoVESPA EU project [93]. Modalities which could penetrate deeper inside tissue partitions also are under exploration, for instance, the UK SonoPill project. It is probable that new strategies for production microarrays for sensing ultrasound will play a crucial role in allowing such sensing capabilities [94].

10. Telemetry

How to transmit and receive data is a principal subject matter in WCE technology. An excessive data rate telemetry system is crucial to permit high-resolution imaging. Due to size constraints and technological limitations of wireless communication, the telemetry subsystem is usually a bottleneck in capsule design. Robotic endoscopic capsules can employ radiofrequency transmission, human body communication, or also can combine a data storage system, thus avoiding wireless communication [95]. Human body technology uses the human body as a conductive medium. It calls less power than radiofrequency communication, however, includes a big wide variety of sensor electrodes at the skin [96]. Wireless capsules using radiofrequency communication are appealing due to their efficient transmission via the layers of the skin. This is particularly genuine for low frequency transmission (UHF-433 ISM and lower) [97]. However, low frequency transmission calls for large electronic components. Given Imaging's capsules embed a Zarlink's transceiver and transmit 2.7 Mb/s at 403–434 MHz. A part of its latest studies focuses on developing impulse radio ultra-wideband antennas (IR-UWB) for WCE [98–100]. A CMOS system using an ON-OFF keying modulation, with a superetherodyne receiver, is provided in [101]. A low power transmitter working within the ISM 434 MHz band is mentioned in [102]. It is designed the use of CMOS 0.13 μm technology and consumes 1.88 mW.

11. Powering

Power control is a prime challenge in WCE, due to dimension constraints and excessive consuming components, consisting of LEDs [103]. Capsules are commonly powered with the aid of using silver oxide button batteries. Two or three of them permit up to 15 h operation [95]. Lithium ion polymer batteries, in addition to thin film batteries, are promising answers to enhance power density and decrease battery dimensions. Wireless power transfer has additionally been investigated. In particular, RF power transfer is tremendously appropriate for clinical devices, on account that it's non-invasive and non-ionizing [93]. An inductive power system, working at 1 MHz and capable of supply 300 mW, is provided in [94]. A portable magnetic electricity transmission system is confirmed in [95]. The system turned into additionally examined on a pig and confirmed an energy conversion efficiency of 2.8 %. An inductive- based wireless recharging system is provided in [96]. It can offer up to at least 1 W power and is capable of recharge a VARTA CP 1254 battery in 20 min. In [97] an analytical assessment amongst simple solenoid, pair of solenoids, double-layer solenoids, segmented-solenoid, and Helmholtz power transmission coils (PTCs) is carried out with a FEM simulation. It indicates that the segmented solenoid PTC can transfer the maximum power.

II. Diagnosis and remedy

Progress in micro-electromechanical structures (MEMS) technology have caused the improvement of recent endoscopic capsules with enhanced diagnostic capabilities, further to traditional visualization of mucosa (embedding, e.g. pressure, pH, blood detection and temperature sensors). However, modern capsule endoscopes lack treatment module(s), accordingly requiring a subsequent conventional endoscopic procedure. Developing clinical capsules with diagnostic, interventional and therapeutic capabilities, consisting of biopsy sampling, clip release for bleeding control, and/or drug delivery, will permit WCE to become the mainstream endoscopic mode. This section is divided into categories: i) diagnosis, and ii) treatment.

1. Diagnosis

With regard to image-based totally diagnosis and derived algorithms for enhanced diagnosis, even supposing a complete 3-D map of the distance covered with the aid of using the diagnostic imaging device isn't always accomplished, 3-D surface shape at unique time instants gives crucial diagnostic information . In particular, those form cues may be used to identify polyp structures; certainly, methods for automatically identifying and analysing them were evolved [98, 99]. While 3-D methods primarily based totally on shading or more than one views are interesting, the maximum clinically applicable advances for computational processing of WCE images were primarily based totally on 2D data. Specifically, automatic abnormality detection and highlighting were investigated and proposed [110–112]. These methods gain notably from latest tendencies in device mastering and particularly convolutional neural networks that have proven to be tremendously able to address detection and segmentation problems. Training data for machine learning methods continues to be an undertaking, however, the network is transferring toward addressing this issue, for instance with the latest EndoVis undertaking at MICCAI 2015 [113]. With regard to more desirable diagnostic inference from capsule images, diverse methods were proposed to enhance the image; however, none have not begun taken into consideration strong appearance and surface tissue shape priors. Enhancing image quality and information is important to lessen the possibilities of lacking potential adenocarcinomas (presently expected round 6 %) [114, 115]. Quick view feature is crucial for permitting realistic evaluation of capsule videos, which may be lengthy [116]. Apart from image enhancement, powerful diagnostic accuracy molecular imaging in gastrointestinal endoscopy has lately emerged as an interesting era encompassing different modalities which could visualize disease-specific morphological or functional tissue changes based on the molecular signature of cells [76, 117]. However, it's far really well worth bringing up that a huge number of endoscopic capsules were designed with embedded sensing capabilities, most of them already available at the market. Gonzalez-Guillaumin et al. [118] evolved a wireless capsule for the detection of gastro-oesophageal reflux ailment. It embeds impedance and pH sensors and makes use of a magnetic holding solution for surgical fixation. Johannessen et al. evolved a wireless multi-sensor system (Lab-in-a-Pill capsule) ready with a control chip, a transmitter, and sensors for pH, conductivity, temperature and dissolved oxygen [119]. The FDA-approved Bravo capsule for pH tracking (produced with the aid of using Given Imaging Ltd.) is a tool for comparing gastroesophageal reflux disease [120].The OMOM pH tablet (Jinshan Science & Technology Co., Ltd., Chongqing, China) is a wireless pH monitoring system now no longer approved by FDA.

It desires to be anchored within the oesophagus and is capable of transmit pH data to an external recorder. The Smart Pill capsule with the aid of using Given Imaging Ltd. is an FDA-approved capsule for evaluation of GI motility. It measures numerous physiological parameters (e.g., pH, pressure and temperature) whilst traveling via the GI tract [121]. CorTemp by HQ Inc. (Palmetto, FL, USA) is an FDA-approved capsule for internal body temperature measurement, with ±0.1 °C accuracy.

The working principle is based on a quartz crystal, embedded into the capsule, whose vibration frequency varies with temperature. Consequently, a magnetic flux is established, and a low-frequency sign flows through the body [122, 123]. In the try to offer much less-invasive procedures for imaging of the GI tract, Check-Cap (Mount Carmel, Israel) is a wireless capsule, which makes use of low-dose radiation to reap the 3-D reconstructed image of the colon. It should mitigate the need for bowel preparation [124]. The HemoPill acute with the aid of using Ovesco Endoscopy AG is a wireless capsule capable to discover acute bleeding in the upper GI tract. It includes an optical sensor capable of discover blood in the organ content in concentrations as low as 1 % [125].

III. WCE SYSTEMS

In the following years, different companies additionally commenced generating new wireless capsules for the digestive tract investigation.

There are five types of capsules for the small bowel, every of them being in short provided in Table I (126).

Capsule	**PillCam™ SB 3 Given Imaging**	**EndoCapsule Olympus America**	**MiroCam® Intromedic**	**OMOM Jianshan**	**CapsoCam CapsoVision**
Size (length/diameter) (mm)	**26.2/11.4**	**26/11**	**24.5/10.8**	**27.9/13**	**31/11**
Weight (g)	**3.00**	**3.50**	**3.25-4.70**	**6.00**	**4.00**
Battery life	**8 h or longer**	**8 h or longer**	**11 h or longer**	**6-8 h or longer**	**15 h**
Resolution	**340x340**	**512x512**	**320x320**	**640x480**	**1,152 x 212**
Frames per sec (fps)	**2 fps or 2-6 fps**	**2 fps**	**3 fps**	**2 fps**	**20 fps**
Field of view (degrees)	**156°**	**145°**	**170°**	**140°**	**360°**
Communication	**RFC**	**RFC**	**Human body communication**	**RFC**	**Onboard storage**

IV. FUTURE PROSPECTIVE

A big variety of patents of capsules for digestive endoscopy were filed worldwide, underlining the interest for those novel devices and field of clinical application. It isn't always viable to offer an exhaustive and detailed patents' evaluation in this manuscript; however, the principal subjects of interest might be highlighted to be able to understand, in some cases, the commercial trends. Inventors and companies are specifically seeking to enhance the features and techniques of these challenging devices, which require high technology and specific interest to patients' comfort and physicians' requests.

For those reasons, over the past years different factors of this topic were studied and developed, including: i) wireless capsule, ii) magnetic guidance, iii) imaging, iv) power source, v) energy management, vi) locomotion mechanism and localization, vii) drug delivery, and vii) biopsy. Different companies, including Olympus, Co., Given Imaging, Ltd, Siemens AG, and university research companies have invested time and sources to expand new ideas for these devices and achieve interesting technological solutions. Some of these are committed to enhance imaging information acquired from cameras placed at the capsule. They use thermal imaging cameras [127] or an internal radiation unit that detects radioactivity unit that detects radioactivity drugs injected into the body [128]. In reality, imaging processing makes it viable to boom comparison withinside the gastrointestinal tract for specific pathologies and morphologies. For example, using infrared or different frequencies of the electromagnetic spectrum permits information that aren't seen through the spectrum to be analysed. Physicians can for that reason enhance their prognosis and higher reply to sickness evolution. Another region beneath Neath exam is the optical section, which incorporates lenses and picture sensors (e.g., CMOS, CCD). Recent tendencies have centred on improving the picture captured from the tablet with the aid of using more than one picture sensors for a round view [129] or on the usage of pictures sensors on the front give up and the rear give up of the tablet [130]. The use of ultrasound and Doppler concepts is a tough subject matter for engineers and researchers, permitting them to contain those technology within the tablets and generate exceptional form of pictures and information of the tested tract [131]. The majority of patents on tablet endoscopy makes a speciality of new strategies for acting locomotion and monitoring the location of the tablet. More specifically, they describe new strategies that rent magnetic guidance - main to magnetic interplay and tablet movement control improvement [132, 133] - or that use an ultrasound positioning system [134]. Power performance is any other subject matter that is under examination, mainly for wi-fi tablets that need to lessen power intake and assure all functions and capabilities over the whole length of the examination (e.g., self-charging approach for the charging of an energy supply with the aid of using an outside electric powered discipline) [135]. Moreover, biopsy mechanisms were advanced to allow the tablet to acquire tissues samples and so enhance examination performance and complexity. This is executed with the aid of using the electro-mechanical solutions to collect and store the sample in the tablet [136, 137]. All those new features and ideas are interesting and some of them promise to bring actual and tangible resource to the evolution of endoscopy with clear benefits for both patients and clinicians.

V. CONCLUSION

Although the advent of WCE in clinical practice at the start of the millennium caused shock waves of change in the field of GI endoscopy, over the previous few years, development has notably slowed down with appreciate to the research advancement and for that reason expectations: that is not directly even proven with the aid of using the fact that, in view that 2009, the variety of recent patent applications are decreasing [138]. Since the appearance of the first capsule endoscope, several IT and robotics studies companies around the world have proposed numerous methods, including algorithms for detecting haemorrhage and lesions, reducing overview time, localizing the capsule or lesion, assessing intestinal motility, providing wireless endoscopic capsule control through accurate magnetic models, locomotion and therapy, and improving video quality. Even though studies are prolific (as measured by publication activity), the technological industrial-orientated development made through the past 5 years can only be taken into consideration as marginal (with appreciate to medical needs and studies-orientated outcomes). Nevertheless, WCE has the capacity to emerge as the main screening, diagnostic and healing approach for the entire GI tract [91]. Moreover, using a robot miniaturized device that promises to provide targeted therapy (e.g., used as a smart active carrier to drug delivery) has been a long-time fascination and – why no longer – unfulfilled dream of the medical profession and the patients alike.

For a device to create the subsequent modern robotic solution for non-invasive prognosis and therapy in the studies discipline of WCE, the aforementioned modules (e.g., powering, telemetry, prognosis and treatment) have to be addressed and properly integrated. Several similarities will be drawn from the field of medicine/gastroenterology and other sciences as well bio-mimetic/bio-stimulated methods, including the spider/insect, worm and fish-like capsules which can be promising methods not only with appreciate to navigation within the digestive tract, however additionally for treatment (e.g., haemostatic clips or drug delivery, biopsies or small dissections) .

Chimeric devices that integrate the quality of both worlds, i.e. conventional and wireless GI endoscopy, appear a promising next step (as in the EndoVESPA EU project [139]). Therefore, following this approach, we trust that GI endoscopy within the third decade of the brand-new millennium becomes an achievement story of screening efficacy and minimal –if any– discomfort. This have to be enhanced version of the capsule - based platform and allied technology, which have to allow, e.g. improved image-capabilities with assistive algorithms [140], and active locomotion [38]. As aeronautical engineering –for more than a century now– has now no longer notably moved far from the conceptual design/concept of the aviation pioneers, the external capsule -like shell of the device - with optimizations of substances and shape [139, 141] - will now no longer change extensively over time. Instead, the speed (and accurate control of the device), the practical characteristics (image definition, illumination, 3-D reconstruction, tactile sensing and therapeutic embedded tool for targeted therapy and in situ drug delivery) and the indications for acquiring it'll change over time. We trust that the generation of assistance or – in a few extreme cases – automation (in prognosis and therapy), an era of universal, equitable, extraordinary GI endoscopy is finally here.

Conflict of Interest

All authors declare no conflicts of interest.

Authors Contribution

Authors have equally participated and shared every item of the work.

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