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Review on Wireless Capsule Endoscopy System Issues, Challenges, and Technologies

***Abstract**. The gold standard for diagnosing disorders of the small bowel is wireless capsule endoscopy (WCE). Capsule endoscopy appears to represent the future of effective diagnostic gastrointestinal (GI) endoscopy. As capsule endoscopy doesn't cause any discomfort, it stands a better chance of being adopted by patients than traditional colonoscopy and gastroscopy, making it a good option for detecting cancer or ulcerations. WCE can be helpful in obtaining images of the GI tract from the inside, but pinpointing exactly where the disease is located is still a major challenge. In this paper, reviewing of the studies dealing with the development of the endoscopy capsule and finding techniques and solutions to provide higher efficiency is presented. Also, the paper showed that the tendency to use artificial intelligence (AI) led to an increase in the accuracy of detecting diseases and a decrease in mistakes caused by physicians' lack of attention or fatigue while reading a video from a capsule, as well as the role of artificial intelligence in shortening the time it takes to read the video. When it comes to WCE, deep learning has shown remarkable success in detecting a wide variety of disorders.*

***Streszczenie.** Złotym standardem w diagnostyce zaburzeń jelita cienkiego jest bezprzewodowa endoskopia kapsułkowa (WCE). Wydaje się, że endoskopia kapsułkowa reprezentuje przyszłość skutecznej endoskopii diagnostycznej przewodu pokarmowego (GI). Ponieważ endoskopia kapsułkowa nie powoduje dyskomfortu, ma większe szanse na przyjęcie przez pacjentów niż tradycyjna kolonoskopia i gastroskopia, co czyni ją dobrą opcją do wykrywania nowotworów czy owrzodzeń. WCE może być pomocne w uzyskiwaniu obrazów przewodu pokarmowego od wewnątrz, ale dokładne określenie lokalizacji choroby nadal stanowi duże wyzwanie. W artykule przedstawiono przegląd badań dotyczących rozwoju kapsuły endoskopowej oraz poszukiwania technik i rozwiązań zapewniających wyższą wydajność. W artykule wykazano również, że tendencja do wykorzystywania sztucznej inteligencji (AI) doprowadziła do zwiększenia dokładności wykrywania chorób i zmniejszenia liczby błędów spowodowanych brakiem uwagi lub zmęczeniem lekarzy podczas czytania wideo z kapsuły, a także Rola sztucznej inteligencji w skróceniu czasu czytania wideo. Jeśli chodzi o WCE, głębokie uczenie się wykazało niezwykły sukces w wykrywaniu szerokiej gamy zaburzeń. (**Przegląd problemów, wyzwań i technologii związanych z bezprzewodowym systemem endoskopii kapsułkowej**)*

Keywords: wireless capsule endoscopy , location tracking, CNN, detection, bowel
Słowa kluczowe: bezprzewodowa endoskopia kapsułkowa, śledzenie lokalizacji, CNN, wykrywanie, jelito

Introduction

The human gastrointestinal (GI) system is among the most complex and mysterious regions inside the human body. The GI tract is separated into four primary parts, such as the esophagus, gastric, small intestine, and large bowel [1]. Because of its length of approximately 9 meters and variable diameters, the digestive system presents numerous obstacles for diagnostic and therapeutic delivery [2]. Infections of the gastrointestinal tract, which include polyps in the ulcer, bleeding, and Crohn's disease, are becoming more common in recent years, despite the fact that ulcers and bleeding have become common illnesses [3]. Traditional methods of assessing digestive system illnesses are X-rays, computer tomography (CT) imaging, imaging with magnetic resonance, and ultrasonography [4]. In X-ray radiography, the small intestine is prominently situated in the image, while the colon surrounds it peripherally. Because bismuth was regarded as excessively hazardous, Krause, Bachem, and Gunther of the Bonn Polyclinic advised barium sulfate as an alternative in 1910. Barium possesses two key properties: it adheres to the small bowel (making the contour, form, and size apparent), and X-rays are absorbed by it, so the original beams are dramatically reduced [5], computer tomography (CT) imaging research techniques have evolved with the medical field. The use of contrast agents has been expanded; later, double-contrast small intestinal examinations were used. Because of the advancement a new approach to imaging studies resulted from the introduction of computerized tomography scanning in 1989. In the early 1990s, CT enterography provided fresh insights into the small intestine. Other non-radiation radiology techniques employed included imaging with magnetic resonance, magnetic resonance enteroclysis (also known as enterography), and contrast-enhanced ultrasound or ultrasonography. These procedures become less intrusive and even more acceptable to patients; however, they do not allow for biopsies [6]. Unfortunately, these devices have low diagnostic results due to their inability to visualize the GI tract wall [4]. This limitation was overcome by endoscopic techniques such as ileocolonoscopy, push enteroscopy, and operative enteroscopy that are intrusive and uncomfortable to patients; however, from an imaging standpoint, they provide real images of the digestive system captured by micro cameras as opposed to images reconstructed by techniques such as radiological examinations [7]. The most frequently used flexible endoscopes allow diagnostic testing of the digestive system (including the esophagus, gastric, and a portion of the small bowel); nonetheless, the bulk of the small intestine remains hard to get to. The discomfort and pain given by elastic endoscopes lower a large number of patients' willingness to undergo such a surgery, which frequently needs sedation [8]. Previously, the detection of a variety conditions was restricted to the upper four feet and lower six feet of the colon and rectum, which are part of the gastrointestinal tract. The method did not provide enough data to determine the kind of illness and the specific afflicted locations inside the gastro-intestinal system. It is a lengthy process that entails the use of a tube and causes the patient pain and discomfort [1]. Considering the limitations of the above imaging methods and the need to see the small intestine in its entirety without pain or anesthesia and without keeping the patient in the hospital during the imaging process, The idea of a capsule endoscopy was introduced for gastrointestinal endoscopy.

I. Wireless Capsule Endoscopy (WCE)

A Look at the Capsule Endoscopy

The instrument invented by Iddan et al. has enabled a pain-free approach to diagnosing the digestive tract [9]. Given Imaging created the first commercial wireless capsule endoscopy system, PillCam, in the year 2000. The Food and Drug Administration (FDA) authorized it in 2001. That has now been 22 years since the first competitive capsule endoscopy was introduced in 2001 [8]. Capsule endoscopy is a convenient and painless way to diagnose digestive issues, especially those of the small intestine. It can take photos of the GI system and send biological data without the use of sedatives, considerably lowering patient pain. These small, swallowable pills are designed to reach restricted areas without the need for surgery [10-12]. Wireless capsule endoscopy (WCE) is a novel method for detecting illnesses of the human digestive system. This technology is promising in terms of efficacy and advancement potential, and it improves convenience by minimizing the complications and discomfort associated with traditional endoscopy. The discovery of a noninvasive device capable of imaging the majority of the small intestine's 15 to 20 feet of mucosa proved transformational. It can help in the prognosis of Crohn's disease, celiac disease, small bowel tumors, unexplained pain in the stomach, and diarrhea [13-16].

Components of an Endoscopy Capsule System

The wireless capsule endoscopy system is made up of four major components: (1) a wireless capsule; (2) a sensor set or a belt with sensors connected to the patient; (3) a data recorder affixed to a belt; and (4) an application-equipped computer workstation [17]. Fig. 1 depicts the system's details

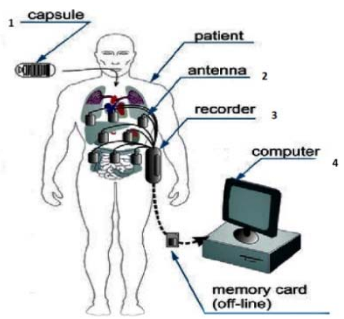


Fig. 1. Shows components of wireless capsule endoscopy system [18]

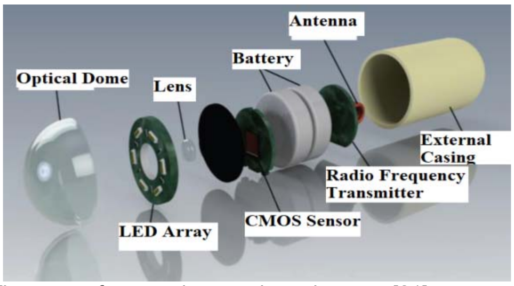


Fig. 2. The parts of a generic capsule endoscope [21]

The endoscopic capsule, (or pill device) is built of a biocompatible material that can tolerate enzymes, stomach acid, and various other reactive compounds [19]. A capsule endoscope typically includes a dome optical, lens, lens holder, CMOS sensor, light-emitting diodes (LED), wireless transmitters employing antennas, and batteries, as shown in Fig. 2 [11][19-20].

A source of light and an image sensor are the two main components of an imaging system. Image sensors are classified into two types: CMOS and CCD. Because of its low power consumption, CMOS technology is becoming increasingly widely used. A WCE's primary goal is to acquire images from inside the body for medical diagnostics [22].

Principle of Wireless Capsule Endoscopy

After one WCE has been ingested by a patient who has been on a diet for approximately 12 hours, this little gadget begins to run and capture images as it goes inside the digestive system. Meanwhile, the images collected by the camera's sensor were wirelessly relayed at a frame rate of 2 frames per second to a belt-mounted receiver. This procedure continues for around 8 hours, or until the wireless capsule endoscope batteries die. lastly, all of the images stored in the record are transferred to a workstation. If necessary, the images must be put into video format, and finally, clinicians can see the images or video and study various causes of GI tract disorders [23-24]. The capsule endoscopy is supposed to normally exit the body after around 24 hours [8].

Types of Capsule Endoscopy

In the capsule endoscopy market, there are five prominent businesses that provide diagnosis equipment non-invasiveness investigations small intestine as well as esophageal and colonic tests. Medtronic Inc., one of those companies, has created the PillCamTMSB3, the third iteration of its small-bowel capsule [25].

There are different wireless CE systems available: PillCamSB (GivenImaging, now medtronic, Ltd., Yokneam, Israel); EndoCapsule (Olympus Medical Systems Co., Japan); MiroCam (IntroMedic Co., South Korea); OMOM (Jinshan Science & Technology, China); and CapsoCamSV1 (CapsoVision, Inc., USA) [17][26]. As shown in Fig. 3,

Fig. 3. Varieties of capsule endoscopes for the small bowel (A) PillCam SB 3; (B) MiroCam; (C) EndoCapsule; (D) OMOM [17]

Capsule endoscope systems are marketed by various suppliers and vary in technology, size and weight of the capsule, number of lenses and antennas, frames per second, and battery life [27]. Table I shows some several forms of capsule endoscopy the small intestine.

TABLE I. DISPLAYS SEVERAL TYPES OF SMALL INTESTINE CAPSULE ENDOSCOPY [28-33]

Capsule	PillCam SB3	MiroCam	EndoCapsul-e10	OMOM HD
Weight(g)	3	3.25	3.3	3
Size(mm)	26.2*11.4	24.5*10.8	26*11	25.4*11
Resolution(pixel)	340*340	320*320	Not available	512*512
Communi-cation	Radio frequency	HBC	Radio frequency	Radio frequenc-y
Frame Rate (fps)	2-6	3	2	2-10
Battery Life(hr)	>=8	11	12	12
Field of view (deg.)	156	170	160	172
Company	Medtronics	Intromedic	Olympus	JinShan

Advantages and Limitations of Wireless Capsule Endoscopy

When compared to other imaging modalities, the advantages of capsule endoscopy are comfort, ease of patient examination, non-invasiveness, and high diagnostic yield. There is no need for sedation. permits direct observation of the colon and small bowel walls (colon capsule endoscopy) [5][34]. The procedure's main drawback is its higher expense compared to alternative techniques; the significant incompletion rate, which has been reported to range from 15% to 30% in several trials; the possibility of capsule retention, which is estimated at 2.6% in Crohn's disease patients and may necessitate surgery to remove the retained capsule; the inability to perform biopsies or provide local therapies because of a lack of motion control [35].

One of the challenges facing the endoscopy capsule is knowing the location of the capsule and locating the images of lesions of the digestive system taken with the endoscopy capsule. Also, some of the problems are due to how long it takes experts to read the entire video that the capsule endoscope captured. To help physicians save time and make an accurate diagnosis, image improvement techniques and automatic detection of bleeding, ulcers, and other diseases of the digestive system were used. In this paper, we present the techniques, solutions, and future directions for the development of the capsule endoscopy system.

II. Some Previous Studies in Capsule Endoscopy

Because of the heterogeneity of the patient's body and the unpredictability of the endoscopic capsule's motion, localization techniques using radio frequency (RF) or even magnetic fields are prone to a large amount of inaccuracy. Bao et al. [36] proposed a motion estimation method to assess the capsule's motion to approximately infer the direction of the capsule endoscope by automatically detecting and segmenting the endoscopic images into sub-regions and classifying them using the Kernel Support Vector Machine (K-SVM). If it is facing the tunnel or the surface of the digestive tract. The results demonstrated that their method is highly accurate (92%). Thus, knowledge of how the capsule moves inside the intestine leads to accurate positioning of the capsule. Fig. 4 (a) and Fig. 4 (b) depict two example facing the tunnel (FT) and face the lumen wall (FL) images, respectively.

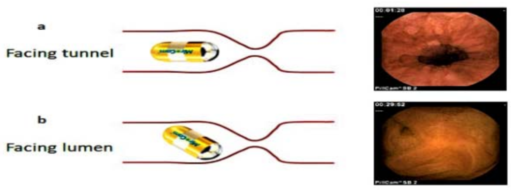


Fig. 4. Images of ((a) facing the tunnel, (b) facing the lumen wall) [36]

While Marya et al. provided radiological validation of 3D localization software embedded in a capsule in 2014 [37], where they used computerized 3D location and a radiographic image approach on thirty suitable volunteers, the average inaccuracy (and standard deviation) among three-dimensional coordinates was determined to be X, 2.00 cm (1.64), Y, 2.64 cm (2.39), and Z, 2.51 cm (1.83). The overall spatial error averaged across all measures was 13.26 cm^3 (22.72). Higher subject body mass indices were associated with inaccuracies in 3D software measurements. Whereas Zeising et al. [38] set out in 2022 to use differential static magnetic localization to measure the distance covered by the capsule endoscope along the prototype digestive tract along with the direction of permanent magnets. The research was carried out on a 487.5 mm-long trajectory that represented a model of the twisting gastrointestinal system, as shown in Fig. 5 The study found that when the magnet's length is at least 5 mm, the average relative distance and orientation errors were not greater than 4.3 ± 3.3% and 2 ± 0.6°, respectively. As a result, a magnet with a length of 5 mm would be well balanced between feasible tracking precision and magnetic volume, both of which are required for incorporation into tiny market capsules.

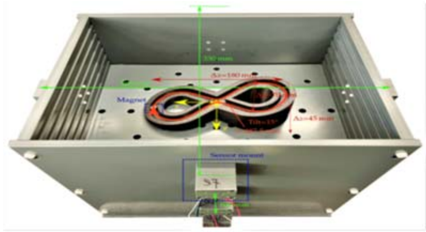


Fig. 5.

Fig. 6. Setup for localization, with 12 sensors placed in the sensor mounts, the setup's coordinate system is located in its center. Example placement of the 10 × 10mm magnet's printed trajectory on the z = 0 mm plane [38]

Studying to recognize the small intestine is a good step to enhance knowing where the capsule is supposed to be and the images taken in it, and thus to know the locations of diseases. Son et al. [39] conducted a study in 2022 on small intestine identification for WCE utilizing convolutional neural networks with temporal filtration, which consist of a deep learning approach (ResNet) followed by a temporal filter (the combination of a median filter and a Savitzky–Golay filter). The study used a database of 200 patients and a total of around 24,000,000 WCE images. In the binary categorization of the small bowel, the research achieved an accuracy of 99.8%. When compared to the underlying data, organ transition points labeled by two gastroenterologists with experience showed transition time errors for the digestive systems of only 38.8 ± 25.8 seconds for the transformation between the stomach and small intestine and 32.0 ± 19.1 seconds for the transfer between the small intestine and large intestine.

As for enhancing the accuracy of diagnosis and reducing the time spent reading the entire imaging video of the endoscopy capsule, in 2011 Figueiredo et al. published research that automates polyp discovery in pillcam colon-2 capsule videos and images. When measured using the protrusion measure (p-value) calculated from input image curvatures on five patients, polyps greater than 1 cm have a P-value greater than 2000, and 80% have a P-value greater than 500. The algorithm correctly identified diverticula, bubbles, waste liquids, and flat lesions as nonprotruding images [40] . Also, Suman et al. [41] distinguished ulcer and non-ulcer pixels using different color spaces. In tests, the algorithm reliably detected ulcers (accuracy: 97.89%; sensitivity: 96.22%; specificity: 95.09%).

Whereas in 2020, Freitas et al. investigated the relationship between traditional video capsule reading and the use of a new RAPID Reader® software tool, TOP100, in the calculation of the Lewis score in Crohn’s disease patients. They tested 115 individuals and discovered a high level of agreement (89.6% of the cases) between the two ways of capsule reading. This study is significant because it illustrates the clinical use of this form of diagnostic tool [42].

The urgent need to discover the causes and locations of gastrointestinal bleeding necessitated researchers' developing techniques for bleeding detection. Pan et al. [43] their study aimed to diagnose bleeding in capsule endoscopy images by measuring color similarity coefficients with two color vector similarity. As a result, it was applied in RGB color space, yielding specificity and sensitivity values of 97% and 90%, respectively. Fig. 6 depicts the images of the confirmed bleeding WCE, whereas Fig. 7 depicts the detection results. In the outcomes, the red, green, and yellow zones represent bleeding, non-bleeding and suspected bleeding respectively.

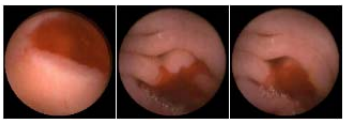


Fig. 7. Detectable Images [43]

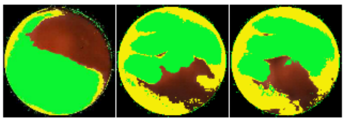


Fig. 8. Depicts the result [43]

While Xiao et al. [44] presented a novel automatic method for detecting hemorrhage focused on a deep convolutional neural network in 2016, they tested their method on a larger dataset of 10,000 WCE images. The method's results demonstrated high performance even with limited data. Also, Saraiva et al. [45] created a convolutional neural network (CNN)-based artificial intelligence algorithm for the automated identification of blood contents in colon capsule endoscopy images in 2021. They based their findings on a sample of 24 CCE examinations (PillCam Colon 2) and 3387259 images. The CNN identified blood with 99.8% sensitivity, 93.2% specificity, 93.8% positive predictive value, and 99.8% negative predictive value. AI-enhanced colonoscopy could be a beneficial test for the assessment of patients with lower intestinal bleeding, especially when standard colonoscopy is unsuitable or the patient is unwilling to undergo it.

Gastrointestinal angiectasia (GIA) is a known vascular malformation that causes a flat, bright-red lesion made up of twisted and crowded capillary dilations in the mucous membrane. GIA represents the most prevalent small intestine vascular lesion and is related to an increased risk of GI hemorrhage. Small bowel capsule endoscope (SB-CE) is the standard examination technique at this time. Its diagnostic yield in individuals with cryptic GI bleeding is approximately 60% [46-47]. Leenhardt et al. developed a computer-assisted diagnosis tool for GI angiectasia, the most popular small bowel (SB) vascular lesion that can bleed, in 2019, as shown in Fig. 8 [48]. They achieved 100% sensitivity, 96% specificity, 96% positive predictive value, and 100% negative predictive value by using CNN-based semantic segmentation.

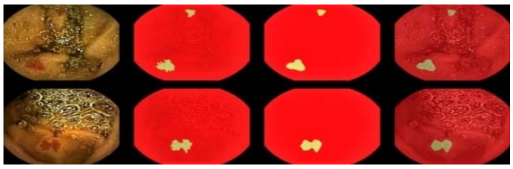
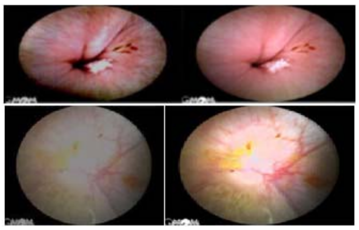


Fig. 9. Depicts the procedure for detecting GI angiectasia. Original still image, annotation image, convolutional neural network (CNN) method, and CNN approach on original still image, from left to right [48]

As for image optimization techniques, Moradi et al. proposed a study in 2015 [49] that aims to improve WCE images' quality through implementing the Structural Similarity Index Measure (SSIM), Peak Signal-to-Noise Ratio (PSNR), and Edge Strength Similarity for Image (ESSIM) parameters in MATLAB R2012a and applying them to a dataset selected by gastroenterologists from OMOM Company that has 500 images of the stomach. Furthermore, the adopted Removing Noise and Contrast Enhancement (RNCE) approach considerably enhanced the quality of capsule endoscope images. Fig. 9 depicts a comparison between the (a) original and (b) improved images.



(a) (b)

Fig. 10. (a) Original Images, and (b) Improved Images [49]

Table II shows a simple comparison among the technologies and studies that are used with WCE.

Table II Latest technology and studies for capsule endoscopy

Ref.	Purpose	Technique	Equipment	samples	Result	algorithm	Advantages	Disadvantages
[40]	Polyp automatic detection	Effective detection technique by using the input image's curvatures	PillCam COLON 2 MATLAB Conventional colonoscopy	Complete examination recordings from five patients	Polyps > 1 cm express a P>2000, 80% of polyps show a P-value > 500	Geometry-based polyp detection	Improving polyp and bulk detection Decreased reading time	The processing time is large
[43]	Blood loss detection	Coefficient of similarity of color	Software	150 videos (14,630) WCE image	Sensitivity 90% Specificity 97%	Color similarity Bleeding detection	Increase its diagnostic yield and time productivity	Old hemorrhage in WCE photos makes the bleeding regions overly dim.
[36]	Estimate the endoscopy capsule's motion	Image classification using Kernel Support Vector Machine (K-SVM)	Intel (R) Core (TM) i5-2400 CPU 3.10 GHz PC	25,600 images	Accuracy 92.67%	Classifier based on the region KSVM	Can be utilized in real-time processing and instead of IMU sensors because to its minimal price and reliability.	The error was brought on by the complicated scene, the lighting, and the unabated noise of the fluids and foam in the GI system.

[37]	Locate the endoscopy capsule	Computerized 3D localization and radiography image	Capsule system , Radiographic image Software	30 healthy volunteers	Average error X, 2.00 cm Y, 2.64 cm Z, 2.51 cm 13.26 cm^3 was the total average spatial error	computerized 3-dimensional localization algorithm	Assist clinicians choose an enteroscopic examination or surgical treatment.	Insufficient testing in patients with small bowel problems
[49]	Enhance the image quality of WCE	Contrast-limited adaptive histogram equalization	MATLAB R2012a	500 actual stomach images from OMOM	Considerably enhance the standard of WCE images RNCE SSIM 0.79 PSNR 35.3 ESSIM 0.9	Algorithm for removing noise with contrast Enhanceme-nt	Offline methods for improving WCE image quality provide more information for diagnosis.	Difficulty evaluating image quality
[44]	Detection of bleeding in WCE images	Deep convolutional neural network	NVIDIA GeForce GTX TITANX	10,000 WCE images	F1 scores reach 0.9955.	DCNN	Lowering the load on physicians.	Not available
[41]	Recognizing ulcer throughout the GIT	Statistical analysis for WCE images	Endocapsule MATLAB R2017a	30 patients 48,000 WCE images	Accuracy 97.89% Sensitivity 96.22% Specificity 95.09%	Feature selection and classification	Increase its diagnostic accuracy and time productivity	Not available
[48]	Detection of GI angioectasia	Deep-feature extraction process and classification, a semantic segmentation images technique coupled with (CNN) was applied.	GIMP Adobe Photoshop CS6 softwares with a Wacom pen tablet linked to a laptop	4166 third-generation SB-CE videos	Sensitivity 100% Specificity 96% Positive predictive value 96%, Negative predictive value of 100%.	Semantic segmentation through CNN	Excellent diagnostic efficiency and time savings Simplify and speed up the process of reading SB-CEs to make it less work.	Rather than full-length films, just still images were analyzed.
[42]	Examinion of the concordance between TOP100 and classic reading (CR) in establishing the Lewis score (LS) in Crohn's disease (CD).	The TOP 100 technique provides a quick and accurate way to assess how much the small intestine is inflamed when someone has Crohn's disease.	PillCam SB3 RAPID Reader software (Given Imaging) version 9.0	115 patients	In 64 patients (55.7%), SBCE discovered of substantial inflammatory activity (LS ≥ 135) , Shows a significant convergence of two methods of reading capsules (Kappa = 0.83, p<.001), and they agreed on 89.6% of the cases.	Top 100	TOP 100 is a rapid and accurate SBCE screening test for moderate-to-severe inflammatory illness, useful in urgent situations. TOP 100 identified major ulcers as well as all stenoses.	The TOP 100 didn't pick up on the mild inflammatory activity which classic reading (CR) did.
[45]	Blood detection system for colon capsule endoscopy (CCE).	CNN for automatic blood detection in CCE images	Xception model Tensorflow 2.3 Keras libraries SciKit learn v. 0.22.2. PillCam software v9	24 CCE exams 3387259 images	Sensitivity (99.8%) Specificity (93.2%) Positive predictive values (93.8%) Negative predictive values (99.8%)	Deep learning algorithm	Increase its diagnostic value and time productivity	Consisting of images collected from a single destination. The technology was only evaluated in still images, and the number of people participating in the research was limited.
[38]	Monitoring the distance traveled by capsule	Differential static magnetic localization	12 LSM303D magnetic sensors Interintegrated	A path of 487.5 mm in length represents a	The average distance relative and orientation	Levenberg–Marquardt (LM) algorithm	Monitoring both traveled distance and direction of capsule	Comparing the trajectory to the average human GIT, it was

	endoscopes and the direction of permanent magnets		circuit (I2C) Arduino board Three neodymium N52 cylindrical permanent magnets with an axial magnetisation of approx. 1150 kA/m 3D-printed trajectory	representation of the convoluted gastrointestinal tract.	errors were under 4.3±3.3% and 2 ±0.6°, respectively, when the magnetic length was at least 5 mm.	ellipsoid fitting algorithm	endoscope throughout a patient's daily life	noticeably shorter.
[39]	Small intestine detection	Convolutional neural networks with temporal filtering	CNN (ResNet50) Temporal filter (Savitzky–Golay filter , median filter)	24,000,000 CE images from 200 patients	99.8 % accuracy in binary classification of the small intestine Transition time mistakes 38.8± 25.8 sec from stomach to small intestine 32 ±19.1 sec from small to large intestine	Automatd organ transition point detection algorithm	In the majority of WCE patients, including aberrant instances such as bleeding, inflammation, and vascular illnesses, the small intestine can be accurately localized.	WCE cases were collected over a lengthy period of time, and it is unclear how this might affect the outcomes and broadness of the AI model.
[50]	Identifying the limits of certain gastrointestinal (GI) organs Real-time monitoring of the WEC	Using convolutional neural networks on capsule endoscopy images	Python Google Colab platform	99 capsule videos extract 5520 images	Average macro precision is 95.56 %, while mean macro sensitivity has been 91.82 %	CNN	When the capsule passes by, clinicians can distinguish the entrances of the four Digestive organs and distinguish the digesting organ	Not available

[a.] P-value: a special formula that determines the degree of protrusion in an image; Kernel SVM: kernel support vector machine; RNCE: removing noise and contrast enhancement; SSIM: structural similarity index measure; PSNR: peak signal-to-noise ratio; ESSIM: edge strength similarity for Image.

Ⅳ. Conxlusion

Many illnesses of the small intestine were challenging to identify prior to the advent of WCE. Using WCE, the entire gastrointestinal system may be detected in a noninvasive manner, leading in a new era in the field of gastrointestinal disease diagnostics. This research paper focuses on most of the studies in the development of wireless capsule endoscopy. One of the important goals of developing capsule endoscopy is to locate the capsule in the digestive system, which in turn leads to knowing the location of the disease. Also among the important goals is reducing the time for reading videos and accurate diagnosis.

It can be said that the use of 3D computerized localization of the video capsule in the abdominal cavity represents a significant contribution to the field of capsule endoscopy because it is a promising new approach for endoscopic capsule localization, where the average inaccuracy (and standard deviation) among three-dimensional coordinates was determined to be X, 2.00 cm (1.64), Y, 2.64 cm (2.39), and Z, 2.51 cm (1.83), the overall spatial error averaged across all measures was 13.26 cm^3 (22.72) for healthy volunteers. Also, it is noticed for the setup coordinate system, the use of fixed magnetic differential determination in tracking the distance, that the capsule endoscope travel along the digestive system model, results average relative distance and orientation errors of values 4.3 mm ± 3.3% and 2 ± 0.6° respectively. However the lack of interference with other magnetic fields should be considered if human body is tested for greater accuracy.

In fact, just as determining the location of the lesion is important, the accuracy and clarity of the image of the endoscopy capsule are no less important. Knowing the location of the lesion without a clear image is considered insufficient for the diagnosis of the case, and vice versa. Therefore, modern technologies (such as artificial intelligence (AI), machine learning and neural network) have been included in order to enhance image clarity and disease location, as well as increase the accuracy and speed of diagnosis and thus provide appropriate treatment for pathological cases.

It is concluded that the using of automatic and computer-aided methods to find gastrointestinal bleeding, such as measuring the similarity of colors with vector color similarity coefficients (like the gray intensity similarity coefficient and the chroma similarity coefficient), presented good results and better suited for video image processing. Nevertheless, it encountered the issue of past bleeding that had darkened the images, making it hard to recognize the bleeding region.

It is noticed that the use of deep convolutional neural network (DCNN) to find bleeding in the images of the endoscopy capsule worked well even with limited data and this technique can be applied in the future to detect other lesions and get more benefit. Therefore for automatic identification of blood or hematologic residues within the lumen of the colon, the CNN is preferred, as long as the artificial intelligence (AI) model is highly sensitive, specific, and accurate for the detection of blood in colon capsule endoscopy (CCE) images. Also, it is recommended to conduct further studies in the future in this field with larger numbers of colonic capsule data. Finally at the present time, these technologies can be considered supportive and not a replacement for the traditional video reading method by specialists in the field.

Although the WCE technology is a bit expensive (not included in health insurance) and not normally used by all the people, however it is an important technology for patients who cannot hold on anesthesia and also those who have already conducted traditional endoscopy.

Thus, future studies and technologies require the acquisition of data from multiple centers to implement this technology in the regular medical use of WCE. Increasing effectiveness and generalization by paying attention to the comprehensiveness of the various gastrointestinal tract lesions.

REFERENCES

[1] Mateen, H., Basar, R., Ahmed, A. U., & Ahmad, M. Y. Localization of wireless capsule endoscope: A systematic review. IEEE Sensors Journal, 17 (5), (2017),1197-1206.

[2] Valdastri, P., Simi, M., & Webster, R. J. Advanced technologies for gastrointestinal endoscopy. Annual Review of Biomedical Engineering, 14, (2012), 397–429. https://doi.org/10.1146/annurev-bioeng-071811-150006

[3] Mohankumar, C. E., Kumar, S. V. D., Senthilkumar, S., Sornagopal, V., & Maharajan, M. S. RNN model-based classification of wireless capsule endoscopy bleeding images.

[4] Basar, M. R., Malek, F., Juni, K. M., Idris, M. S., & Saleh, M. I. M. Ingestible wireless capsule technology: A review of development and future indication. International Journal of Antennas and Propagation, (2012 Dec); 2012.

[5] Ionescu, A. G., Glodeanu, A. D., Ionescu, M., Zaharie, S. I., Ciurea, A. M., Golli, A. L., ... & Vere, C. C. Clinical impact of wireless capsule endoscopy for small bowel investigation. Experimental and Therapeutic Medicine, 23 (2022), (4), 1-9.

[6] Ilangovan, R., Burling, D., George, A., Gupta, A., Marshall, M., & Taylor, S. A. CT enterography: review of technique and practical tips. The British journal of radiology, 85 (2012), (1015), 876-886.

[7] Markova, I., Kluchova, K., Zboril, R., Mashlan, M., & Herman, M. Small bowel imaging-still a radiologic approach. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub, 154 (2), (2010),123-132.

[8] Khan, T. H., Shrestha, R., Wahid, K. A., & Babyn, P. Design of a smart-device and FPGA based wireless capsule endoscopic system. Sensors and Actuators A: Physical, 221, (2015), 77-87.

[9] Sekuboyina, A. K., Devarakonda, S. T., & Seelamantula, C. S. A convolutional neural network approach for abnormality detection in wireless capsule endoscopy. In 2017 IEEE 14th International Symposium on Biomedical Imaging (ISBI 2017) (2017, April), (pp. 1057-1060). IEEE.

[10] Lu, B.. Image Aided Recognition of Wireless Capsule Endoscope Based on the Neural Network. Journal of Healthcare Engineering, (2022), 2022.

[11] Wang, G. B., Xuan, X. W., Jiang, D. L., Li, K., & Wang, W. A miniaturized implantable antenna sensor for wireless capsule endoscopy system. AEU-International Journal of Electronics and Communications, (2022), 143, 154022.

[12] Alam, M. W., Vedaei, S. S., & Wahid, K. A. A fluorescence-based wireless capsule endoscopy system for detecting colorectal cancer. Cancers, 12 (2020), (4), 890.

[13] Shamsan, Z. A. Spectrum sharing between wireless medical capsule endoscopy and LTE system. Alexandria Engineering Journal, 61 (2022), (12), 10283-10305.

[14] Cave, D. R., Hakimian, S., & Patel, K. Current controversies concerning capsule endoscopy. Digestive Diseases and Sciences, (2019), 64, 3040-3047.

[15] Kim, S. H., & Chun, H. J. Capsule endoscopy: Pitfalls and approaches to overcome. Diagnostics, 11 (2021), (10), 1765.

[16] Khaleghi, A., & Balasingham, I. Wireless communication link for capsule endoscope at 600 MHz. In 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) (2015, August), (pp. 4081-4084). IEEE.

[17] Van de Bruaene, C., De Looze, D., & Hindryckx, P. Small bowel capsule endoscopy: Where are we after almost 15 years of use?. World journal of gastrointestinal endoscopy, 7 (2015), (1), 13.

[18] Koprowski, R. Overview of technical solutions and assessment of clinical usefulness of capsule endoscopy. Biomedical engineering online, (2015), 14, 1-23.

[19] Osagie, M. S. U., Enagbonma, O., & Inyang, A. I. (2018). Structural dynamics and evolution of capsule endoscopy (pill camera) technology in gastroenterologist assertion. arXiv preprint arXiv:1804.01171.

[20] Davis, B. R., Harris, H., & Vitale, G. C. The evolution of endoscopy: wireless capsule cameras for the diagnosis of occult gastrointestinal bleeding and inflammatory bowel disease. Surgical innovation, 12 (2005), (2), 129-133.

[21] Brown, A. P., & Jayatissa, A. H. Analysis of current and future technologies of capsule endoscopy: A mini review. Arch. Preventive Med., 5 (2020), (1), 31-34.

[22] Noormohammadi, R., Khaleghi, A., & Balasingham, I. Battery-free wireless communication for video capsule endoscopy. In 2019 13th International Symposium on Medical Information and Communication Technology (ISMICT) (2019, May), (pp. 1-5). IEEE.

[23] Ezatian, R., Khaledyan, D., Jafari, K., Heidari, M., Khuzani, A. Z., & Mashhadi, N. Image quality enhancement in wireless capsule endoscopy with adaptive fraction gamma transformation and unsharp masking filter. In 2020 IEEE Global Humanitarian Technology Conference (GHTC) (2020), (pp. 1-7). IEEE.

[24] Pan, G., & Wang, L. (2011). Swallowable wireless capsule endoscopy: Progress and technical challenges. Gastroenterology research and practice, 2012.

[25] Vasilakakis, M., Koulaouzidis, A., Marlicz, W., & Iakovidis, D. The future of capsule endoscopy in clinical practice: from diagnostic to therapeutic experimental prototype capsules. Gastroenterology Review/Przegląd Gastroenterologiczny, 15 (2020), (3), 179-193.

[26] Karargyris, A., & Koulaouzidis, A. OdoCapsule: next-generation wireless capsule endoscopy with accurate lesion localization and video stabilization capabilities. IEEE Transactions on Biomedical Engineering, 62 (2014), (1), 352-360.

[27] Ghoshal, U. C., & Amornyotin, S. Capsule endoscopy: A new era of gastrointestinal endoscopy (2013), (pp. 75-88). Rijeka, Crotia: InTech.

[28] Sliker, L. J., & Ciuti, G. Flexible and capsule endoscopy for screening, diagnosis and treatment. Expert review of medical devices, 11(2014), (6), 649-666.

[29] Ciuti, G., Menciassi, A., & Dario, P. Capsule endoscopy: from current achievements to open challenges. IEEE reviews in biomedical engineering, (2011), 4, 59-72.

[30] Baptista, V., Marya, N., Singh, A., Rupawala, A., Gondal, B., & Cave, D. R. (2014). Continuing challenges in the diagnosis and management of obscure gastrointestinal bleeding.

[31] Jensen, M. D., Brodersen, J. B., & Kjeldsen, J. Capsule endoscopy for the diagnosis and follow up of Crohn's disease: a comprehensive review of current status. Annals of Gastroenterology: Quarterly Publication of the Hellenic Society of Gastroenterology, 30 (2017), (2), 168.

[32] Song, H. J., & Shim, K. N. (2016). Current status and future perspectives of capsule endoscopy. Intestinal Research, 14(1), 21.

[33] Pennazio, M. Capsule endoscopy. Endoscopy, 37 (2005), (11), 1073-1078.

[34] Kwack, W. G., & Lim, Y. J. Current status and research into

overcoming limitations of capsule endoscopy. Clinical endoscopy, 49 (2016), (1), 8-15.
[35] Mitselos, I. V., Christodoulou, D. K., Katsanos, K. H., & Tsianos, E. V. Role of wireless capsule endoscopy in the follow-up of inflammatory bowel disease. World journal of gastrointestinal endoscopy, 7 (2015), (6), 643.
[36] Bao, G., & Pahlavai, K. Motion estimation of the endoscopy capsule using region-based Kernel SVM classifier. In IEEE International Conference on Electro-Information Technology, EIT 2013 (2013, May), (pp. 1-5). IEEE.
[37] Marya, N., Karellas, A., Foley, A., Roychowdhury, A., & Cave, D. Computerized 3-dimensional localization of a video capsule in the abdominal cavity: validation by digital radiography. Gastrointestinal endoscopy, 79 (2014), (4), 669-674.
[38] Zeising, S., Chen, L., Thalmayer, A., Lübke, M., Fischer, G., & Kirchner, J. Tracking the traveled distance of capsule endoscopes along a gastrointestinal-tract model using differential static magnetic localization. Diagnostics, 12 (2022), (6), 1333.
[39] Son, G., Eo, T., An, J., Oh, D. J., Shin, Y., Rha, H., ... & Hwang, D. Small Bowel Detection for Wireless Capsule Endoscopy Using Convolutional Neural Networks with Temporal Filtering. Diagnostics, 12 (2022), (8), 1858.
[40] Figueiredo, P. N., Figueiredo, I. N., Prasath, S., & Tsai, R. Automatic polyp detection in pillcam colon 2 capsule images and videos: Preliminary feasibility report. Diagnostic and Therapeutic Endoscopy, (2011), 2011.
[41] Suman, S., Hussin, F. A., Malik, A. S., Ho, S. H., Hilmi, I., Leow, A. H. R., & Goh, K. L. Feature selection and classification of ulcerated lesions using statistical analysis for WCE images. Applied Sciences, 7 (2017), (10), 1097.
[42] Freitas, M., Arieira, C., Carvalho, P. B., Rosa, B., Moreira, M. J., & Cotter, J. Simplify to improve in capsule endoscopy–TOP 100 is a swift and reliable evaluation tool for the small bowel inflammatory activity in Crohn's disease. Scandinavian Journal of Gastroenterology, 55 (2020), (4), 408-413.
[43] Pan, G. B., Xu, F., & Chen, J. L. Bleeding detection in wireless capsule endoscopy using color similarity coefficient. In Applied Mechanics and Materials (2012), (Vol. 195, pp. 307-312). Trans Tech Publications Ltd.
[44] Jia, X. Meng MQ. In A deep convolutional neural network for bleeding detection in Wireless Capsule Endoscopy images. Annu Int Conf IEEE Eng Med Biol Soc (2016, August), (Vol. 2016, pp. 639-642).
[45] Mascarenhas Saraiva, M., Ferreira, J. P. S., Cardoso, H., Afonso, J., Ribeiro, T., Andrade, P., Parente, M. P. L., Jorge, R. N., & Macedo, G. Artificial intelligence and colon capsule endoscopy: automatic detection of blood in colon capsule endoscopy using a convolutional neural network. Endoscopy International Open, 09 (2021), (08), E1264–E1268. https://doi.org/10.1055/a-1490-8960
[46] Becq, A., Rahmi, G., Perrod, G., & Cellier, C. Hemorrhagic angiodysplasia of the digestive tract: pathogenesis, diagnosis, and management. Gastrointestinal endoscopy, 86 (2017), (5), 792-806.
[47] Pons-Beltrán, V. Obscure gastrointestinal bleeding and" obscure" capsule. May we switch on any lights?. Revista Espanola de Enfermedades Digestivas: Organo Oficial de la Sociedad Espanola de Patologia Digestiva, 107 (2015), (12), 711-712.
[48] Leenhardt, R., Vasseur, P., Li, C., Saurin, J. C., Rahmi, G., Cholet, F., ... & Romain, O. A neural network algorithm for detection of GI angiectasia during small-bowel capsule endoscopy. Gastrointestinal endoscopy, 89 (2019), (1), 189-194.
[49] Moradi, M., Falahati, A., Shahbahrami, A., & Zare-Hassanpour, R. Improving visual quality in wireless capsule endoscopy images with contrast-limited adaptive histogram equalization. In 2015 2nd International Conference on Pattern Recognition and Image Analysis (IPRIA) (2015, March), (pp. 1-5). IEEE.
[50] Athanasiou, S. A., Sergaki, E. S., Polydorou, A. A., Polydorou, A. A., Stavrakakis, G. S., Afentakis, N. M., ... & Zervakis, M. E. Revealing the Boundaries of Selected Gastro-Intestinal (GI) Organs by Implementing CNNs in Endoscopic Capsule Images. Diagnostics, 13 (2023), (5), 865.