European Journal of Computer Science and Information Technology, 12 (2),65-74, 2024
Print ISSN: 2054-0957 (Print),
Online ISSN: 2054-0965 (Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

A Survey on Techniques of Wireless Capsule Endoscopy for Image Enhancement and Disease Detection

Noora Mazin Sheet[1], Ziyad k. Farej[2], Amer Farhan Sheet[3]
[1,2,3] Northern Technical University, Technical Engineering College of Mosul, Iraq
Corresponding author: noora.mazin@ntu.edu.iq

doi: https://doi.org/10.37745/ejcsit.2013/vol12n26574 Published April 27, 2024

Citation: Sheet N.M., Farej Z.K., and Sheet A.F. (2024) A Survey on Techniques of Wireless Capsule Endoscopy for Image Enhancement and Disease Detection, *European Journal of Computer Science and Information Technology*, 12 (2),65-74

ABSTRACT: *Wireless capsule endoscopy (WCE) is the gold standard for diagnosing small bowel disorders and is considered the future of effective diagnostic gastrointestinal (GI) endoscopy. Patients find it comfortable and more likely to adopt it than traditional colonoscopy and gastroscopy, making it a viable option for detecting cancer or ulcerations. WCE can obtain images of the GI tract from the inside, but pinpointing the disease's location remains a challenge. This paper reviews studies on endoscopy capsule development and discusses techniques and solutions for higher efficiency. Research has demonstrated that artificial intelligence (AI) enhances the accuracy of disease detection and minimizes errors resulting from physicians' fatigue or lack of attention. When it comes to WCE, deep learning has shown remarkable success in detecting a wide variety of disorders.*

KEYWORDS: wireless capsule endoscopy, location, detection, CNN, bowel

INTRODUCTION

The human gastrointestinal tract (GI) is one of the most complex and intriguing regions of the body. The esophagus, stomach, small intestinal tract, and large bowel are the four sections that make up the GI tract (Mateen et al., 2017). Because of its length of roughly 9 meters and various diameters, the digestive tract poses several diagnostic and therapeutic challenges (Valdastri et al., 2012). Diseases of the gastrointestinal system, such as ulcer polyps, hemorrhage, and Crohn's disease, have grown increasingly widespread in recent years, despite knowing that ulcers and bleeding are common disorders (Mohankumar et al., 2022).

X-rays, computed tomography (CT) imaging, magnetic resonance imaging, and ultrasonography are traditional approaches for diagnosing digestive system diseases (Basar et al., 2012). These procedures become less invasive and more acceptable to patients; however, they do not allow for biopsies. Unfortunately, these instruments provide limited diagnostic findings owing to their inability to visualize the intestinal wall.

Endoscopic techniques such as ileocolonoscopy, push enteroscopy, and operative enteroscopy have overcome this limitation, although they are intrusive and uncomfortable for patients. From an imaging perspective, these techniques provide real images of the digestive system captured by microcameras, as opposed to images reconstructed by techniques like radiological examinations (Markova et al., 2010).The most commonly used flexible endoscopes may perform diagnostic tests on the digestive system (including the esophagus, stomach, and a section of the small bowel); nonetheless, the majority of the small intestine remains difficult to access. Elastic endoscopes' discomfort and agony often discourage many patients from undergoing the procedure, which typically necessitates anesthesia (Khan et al., 2015).

Previously, it could only detect a number of disorders in the upper four feet and lower six feet of the colon and rectum. The approach did not offer enough information to identify the kind of sickness and the particular affected areas of the gastro-intestinal tract. It is a lengthy procedure that necessitates the use of a tube, causing the patient pain and discomfort (Mateen et al., 2017).Given the limitations of the previous imaging technologies, as well as the necessity to observe the whole small intestine without discomfort or anesthesia and without putting the patient in the hospital throughout the imaging procedure, the concept of a capsule endoscopy for gastrointestinal endoscopy was proposed.

WIRELESS CAPSULE ENDOSCOPY (WCE)

A brief description of capsule endoscopy

Iddan et al. developed equipment for painless digestive system diagnostics (Sekuboyina et al., 2017). In 2000, Given Imaging created PillCam, the first commercial wireless capsule endoscopy equipment. The Food and Drug Administration (FDA) authorised it in 2001 (Khan et al., 2015). Capsule endoscopy is a simple and painless way to discover digestive issues, especially those involving the small intestine. It can picture the digestive system and send biological data without the use of sedatives, considerably lowering patient discomfort. These little, swallowable pills are designed to target specific regions, avoiding the need for surgery (Wang et al., 2022)(Alam et al., 2020). This approach offers hope in terms of efficacy and future improvement, as well as convenience by reducing the challenges and discomfort associated with typical endoscopic procedures. It may help in the diagnosis of Crohn's disease, celiac disease, small bowel tumours, and stomach pain (Shamsan, 2022)(Kim & Chun, 2021).

Parts and Concept of an Endoscopic Capsule Device

The wireless capsule endoscopy system consists of a wireless capsule, a sensor set or belt with sensors linked to the patient, a data recorder attached to the belt, and an application-equipped computer workstation (Cedric Van de Bruaene, Danny De Looze & Cedric, 2015).

Endoscopic capsules are made of materials that are biocompatible that can withstand enzymes, stomach acid, and other reactive substances. A capsule endoscope generally incorporates a dome-shaped optical, lens, lens holder, CMOS sensor, light-emitting diodes (LED), wireless transmitters with antenna, and batteries, as depicted in Figure 1 (Osagie et al., 2018)(Davis et al., 2005).

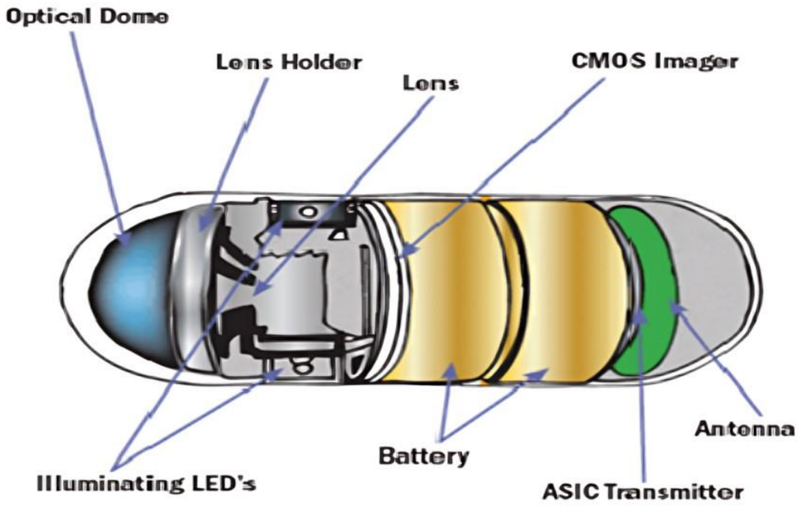

Figure 1. The parts of a generic capsule endoscope (Quentin Angermann, Aymeric Histace, Olivier Romain, Xavier Dray, Andrea Pinna & Abstract, 2015).

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. The capsule endoscopy is supposed to normally exit the body after around 24 hours (Khan et al., 2015)(Ezatian et al., 2020).

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 (Kwack & Lim, 2016). 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 (Mitselos et al., 2015).

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 and future directions for the development of the capsule endoscopy system.

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. Marya et al. provided radiological validation of 3D localization software embedded in a capsule in 2014 (Marya et al., 2014), 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 cm3 (22.72).

The urgent need to discover the causes and locations of gastrointestinal bleeding necessitated researchers' developing techniques for bleeding detection. Pan et al. (Pan et al., 2012) 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. Figure 2 depicts the images of the confirmed bleeding WCE, and the detection results. In the outcomes, the red, green, and yellow zones represent bleeding, non-bleeding and suspected bleeding respectively.

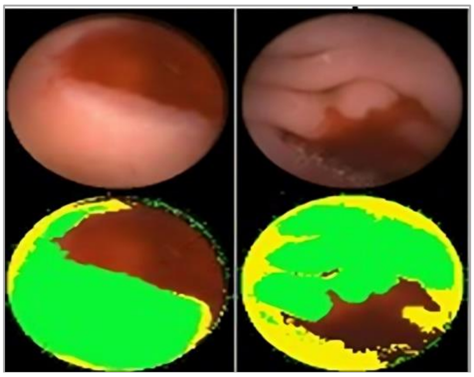

Figure 2. (a) Detectable Images, (b) Depicts the result (Pan et al., 2012).

While Xiao et al. (Jia & Meng, 2016) 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. (Mascarenhas Saraiva et al., 2021) 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.

As for enhancing the accuracy of diagnosis and reducing the time spent reading the entire imaging video of the endoscopy capsule, Suman et al. (Suman et al., 2017) 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%).

As for image optimization techniques, Moradi et al. proposed a study in 2015 (Moradi et al., 2015) 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. Figure 3 depicts a comparison between the (a) original and (b) improved images.

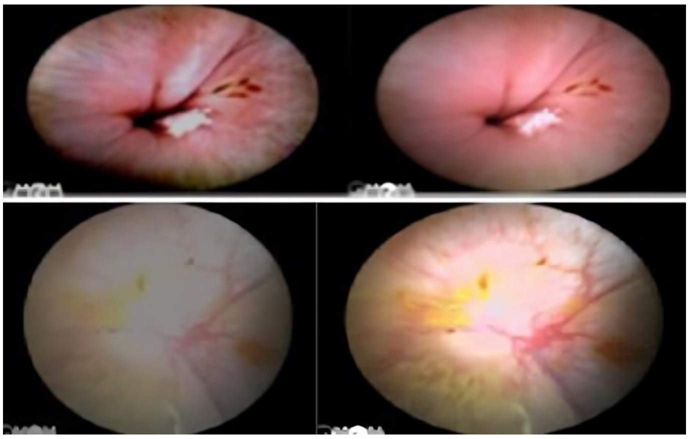

Figure 3. (a) Original Images, and (b) Improved Images (Moradi et al., 2015)**.**

Table 1 shows a simple comparison among the technologies and studies that are used with WCE.

Table 1. Latest technology and studies for capsule endoscopy

Ref.	Purpose	Technique	samples	Result	algorithm	Advantages	Disadvantages
Pan et al., 2012)	Blood loss detection	Coefficient of similarity of color	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.
Marya et al., 2014	Locate the endoscopy capsule	Computerized 3D localization and radiography image	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
(Moradi et al., 2015)	Enhance the image quality of WCE	Contrast-limited adaptive histogram equalization	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 Enhance me-nt	Offline methods for improving WCE image quality provide more information for diagnosis.	Difficulty evaluating image quality
Jia & Meng, 2016	Detection of bleeding in WCE images	Deep convolutional neural network	10,000 WCE images	F1 scores reach 0.9955.	DCNN	Lowering the load on physicians.	Not available
(Suman et al., 2017)	Recognizing ulcer throughout the GIT	Statistical analysis for WCE images	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

(Mascarenhas Saraiva et al., 2021)	Blood detection system for colon capsule endoscopy (CCE).	CNN for automatic blood detection in CCE images	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.
(Athanasiou et al., 2023)	Identifying the limits of certain gastrointestinal (GI) organs Real-time monitoring of the WEC	Using convolutional neural networks on capsule endoscopy images	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. RNCE: removing noise and contrast enhancement; SSIM: structural similarity index measure; PSNR: peak signal-to-noise ratio; ESSIM: edge strength similarity for Image.

CONCLUSION

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 to a new era in the field of gastrointestinal disease diagnostics. This research paper focuses on some 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 spent reading videos and making accurate diagnoses.

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 cm3 (22.72) for healthy volunteers. 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

Alam, M. W., Vedaei, S. S., & Wahid, K. A. (2020). A fluorescence-based wireless capsule endoscopy system for detecting colorectal cancer. *Cancers*, *12*(4). https://doi.org/10.3390/cancers12040890

Athanasiou, S. A., Sergaki, E. S., Polydorou, A. A., Polydorou, A. A., Stavrakakis, G.

S., Afentakis, N. M., Vardiambasis, I. O., & Zervakis, M. E. (2023). *Revealing the Boundaries of Selected Gastro-Intestinal (GI) Organs by Implementing CNNs in Endoscopic Capsule Images*.

Basar, M. R., Malek, F., Juni, K. M., Idris, M. S., & Saleh, M. I. M. (2012). Ingestible wireless capsule technology: A review of development and future indication. *International Journal of Antennas and Propagation*, *2012*, 14. https://doi.org/10.1155/2012/807165

Cedric Van de Bruaene, Danny De Looze, P. H., & Cedric. (2015). Small bowel capsule endoscopy: Where are we after almost 15 years of use? *World Journal of Gastrointestinal Endoscopy*, *7*(1), 13. https://doi.org/10.4253/wjge.v7.i1.13

Davis, B. R., Harris, H., & Vitale, G. C. (2005). The evolution of endoscopy: Wireless capsule cameras for the diagnosis of occult gastrointestinal bleeding and inflammatory bowel disease. *Surgical Innovation*, *12*(2), 129–133. https://doi.org/10.1177/155335060501200210

Ezatian, R., Khaledyan, D., Jafari, K., Heidari, M., Khuzani, A. Z., & Mashhadi, N. (2020). Image quality enhancement in wireless capsule endoscopy with Adaptive Fraction Gamma Transformation and Unsharp Masking filter. *2020 IEEE Global Humanitarian Technology Conference, GHTC 2020*. https://doi.org/10.1109/GHTC46280.2020.9342851

Jia, X., & Meng, M. Q. H. (2016). A deep convolutional neural network for bleeding detection in Wireless Capsule Endoscopy images. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*, *2016-Octob*, 639–642. https://doi.org/10.1109/EMBC.2016.7590783

Khan, T. H., Shrestha, R., Wahid, K. A., & Babyn, P. (2015). Design of a smart-device and FPGA based wireless capsule endoscopic system. *Sensors and Actuators, A: Physical*, *221*, 77–87. https://doi.org/10.1016/j.sna.2014.10.033

Kim, S. H., & Chun, H. J. (2021). Capsule endoscopy: Pitfalls and approaches to overcome. *Diagnostics*, *11*(10). https://doi.org/10.3390/diagnostics11101765

Kwack, W. G., & Lim, Y. J. (2016). Current status and research into overcoming limitations of capsule endoscopy. *Clinical Endoscopy*, *49*(1), 8–15. https://doi.org/10.5946/ce.2016.49.1.8

Markova, I., Kluchova, K., Zboril, R., Mashlan, M., & Hermanc, M. (2010). Small bowel imaging - Still a radiologic approach? *Biomedical Papers*, *154*(2), 123–132. https://doi.org/10.5507/bp.2010.019

Marya, N., Karellas, A., Foley, A., Roychowdhury, A., & Cave, D. (2014). Computerized 3-dimensional localization of a video capsule in the abdominal cavity: Validation by digital radiography. *Gastrointestinal Endoscopy*, *79*(4), 669–674. https://doi.org/10.1016/j.gie.2013.11.022

Mascarenhas Saraiva, M., Ferreira, J. P. S., Cardoso, H., Afonso, J., Ribeiro, T., Andrade, P., Parente, M. P. L., Jorge, R. N., & Macedo, G. (2021). Artificial intelligence and colon capsule endoscopy: automatic detection of blood in colon capsule endoscopy using a convolutional neural network. *Endoscopy International Open*, *09*(08), E1264–E1268. https://doi.org/10.1055/a-1490-8960

Mateen, H., Basar, R., Ahmed, A. U., & Ahmad, M. Y. (2017). Localization of Wireless Capsule Endoscope: A Systematic Review. *IEEE Sensors Journal*, *17*(5), 1197–

1206. https://doi.org/10.1109/JSEN.2016.2645945

Mitselos, I. V, Christodoulou, D. K., Katsanos, K. H., & Tsianos, E. V. (2015). Role of wireless capsule endoscopy in the follow-up of inflammatory bowel disease. *World Journal of Gastrointestinal Endoscopy*, *7*(6), 643. https://doi.org/10.4253/wjge.v7.i6.643

Mohankumar, C. E., Kumar, S. V. D., Senthilkumar, S., Sornagopal, V., & Maharajan, M. S. (2022). RNN model-based classification of wireless capsule endoscopy bleeding images. *International Journal of Health Sciences*, *6*(March), 7330–7344. https://doi.org/10.53730/ijhs.v6ns1.6910

Moradi, M., Falahati, A., Shahbahrami, A., & Zare-Hassanpour, R. (2015). Improving visual quality in wireless capsule endoscopy images with contrast-limited adaptive histogram equalization. *2015 2nd International Conference on Pattern Recognition and Image Analysis, IPRIA 2015, Ipria*, 1–5. https://doi.org/10.1109/PRIA.2015.7161645

Osagie, M. S. U., Enagbonma, O., & Inyang, A. I. (2018). Structural Dynamics and Evolution of Capsule Endoscopy (Pill Camera) Technology in Gastroenterologists Assertion. *International Journal in Foundations of Computer Science & Technology*, *8*(1/2), 01–12. https://doi.org/10.5121/ijfcst.2018.8201

Pan, G., Xu, F., & Chen, J. (2012). Bleeding detection in wireless capsule endoscopy using color similarity coefficient. *Applied Mechanics and Materials*, *195–196*, 307–312. https://doi.org/10.4028/www.scientific.net/AMM.195-196.307

Quentin Angermann, Aymeric Histace, Olivier Romain, Xavier Dray, Andrea Pinna, and B. G., & Abstract. (2015). Smart Videocapsule for Early Diagnosis of Colorectal Cancer: Toward Embedded Image Analysis. *Computational Intelligence in Digital and Network Designs and Applications*, *May*, 1–245. https://doi.org/10.1007/978-3-319-20071-2

Sekuboyina, A. K., Devarakonda, S. T., & Seelamantula, C. S. (2017). A convolutional neural network approach for abnormality detection in Wireless Capsule Endoscopy. *Proceedings - International Symposium on Biomedical Imaging*, 1057–1060. https://doi.org/10.1109/ISBI.2017.7950698

Shamsan, Z. A. (2022). Spectrum sharing between wireless medical capsule endoscopy and LTE system. *Alexandria Engineering Journal*, *61*(12), 10283–10305. https://doi.org/10.1016/j.aej.2022.03.072

Suman, S., Hussin, F. A., Malik, A. S., Ho, S. H., Hilmi, I., Leow, A. H. R., & Goh, K. L. (2017). Feature selection and classification of ulcerated lesions using statistical analysis for WCE images. *Applied Sciences (Switzerland)*, *7*(10). https://doi.org/10.3390/app7101097

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

Wang, G. bo, Xuan, X. wei, Jiang, D. lian, Li, K., & Wang, W. (2022). A miniaturized implantable antenna sensor for wireless capsule endoscopy system. *AEU - International Journal of Electronics and Communications*, *143*(August 2021). https://doi.org/10.1016/j.aeue.2021.154022