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CAPSULE ENDOSCOPY (A NEW REVOLUTION USING ARTIFICIAL INTELLIGENCE)

Mayuri walke, Atharva Vedpathak, Payal Deshmukh

Student, Asst. Professor

Artificial Intelligence & Data Science,

Ajeenkya DY Patil School of Engineering, Pune, India

Abstract *:* Capsule endoscopy has transformed the management of small-bowel diseases due to its convenience and non-invasive nature. It is a widely employed technique for assessing conditions such as obscure gastrointestinal bleeding, Crohn's disease, small-bowel tumours, and polyposis syndrome. Nevertheless, challenges such as the time-consuming interpretation process, oversight of small-bowel lesions, and the absence of mobility hinder its broader application. In conjunction with recent strides in artificial intelligence, numerous studies have highlighted the promising capabilities of convolutional neural network systems in diagnosing various small-bowel abnormalities, such as erosion/ulcers, Angio ectasias, polyps, and bleeding lesions. These advancements have significantly decreased the time required for interpreting capsule endoscopy results. Additionally, investigations into clinical applications include colon capsule endoscopy and the use of magnetic force for capsule endoscopy locomotion. Diverse prototypes of capsule endoscopy have been introduced to facilitate active mobility, biopsy, or therapeutic interventions. This review aims to explore recent progress in artificial intelligence applied to capsule endoscopy and delve into research on other technological enhancements in this field.

I. INTRODUCTION

The advent of capsule endoscopy, coupled with the integration of artificial intelligence (AI), marks a transformative era in gastrointestinal diagnostics. Capsule endoscopy, introduced as a pioneering non-invasive technique, now harnesses the power of AI to revolutionize the way we investigate and understand the complexities of the digestive system. This symbiotic relationship between advanced imaging technology and AI capabilities has redefined the landscape of medical diagnostics, particularly in the realm of small-bowel exploration. The marriage of capsule endoscopy and artificial intelligence not only enhances the precision and efficiency of detecting abnormalities but also paves the way for unprecedented advancements in the field, promising a more streamlined, insightful, and patient-centric approach to gastrointestinal health assessment. Since the inception of the inaugural capsule endoscope in the year 2000, capsule endoscopy (CE) has evolved into a crucial non-invasive method for exploring and diagnosing diseases of the small bowel (SB). This innovative device is capable of traversing the entirety of the gastrointestinal (GI) tract, enabling the identification of mucosal abnormalities in the SB that traditional endoscopes are unable to access. Moreover, the widespread adoption of capsule endoscopy (CE) is attributed to its user-friendly Fuse design, patient-friendly experience, and emphasis on safety. Over time, CE has emerged as the primary investigative tool for cases of obscure gastrointestinal (GI) bleeding and has played a pivotal role in assessing Crohn's disease, small-bowel tumors, and monitoring polyposis syndromes . Nevertheless, the utilization of CE is not without its challenges, including the laborious and monotonous nature of the reading process, the absence of active mobility, the incapacity to acquire biopsies, and the inability to conduct therapeutic interventions such as drug delivery. To address these limitations, various research groups are actively developing novel technologies, with a particular focus on integrating artificial intelligence (AI) into the realm of CE, aligning with the recent advancements in AI. This discussion outlines AI approaches for identifying small-bowel abnormalities using CE and introduces recent studies exploring innovative technologies within the CE domain.

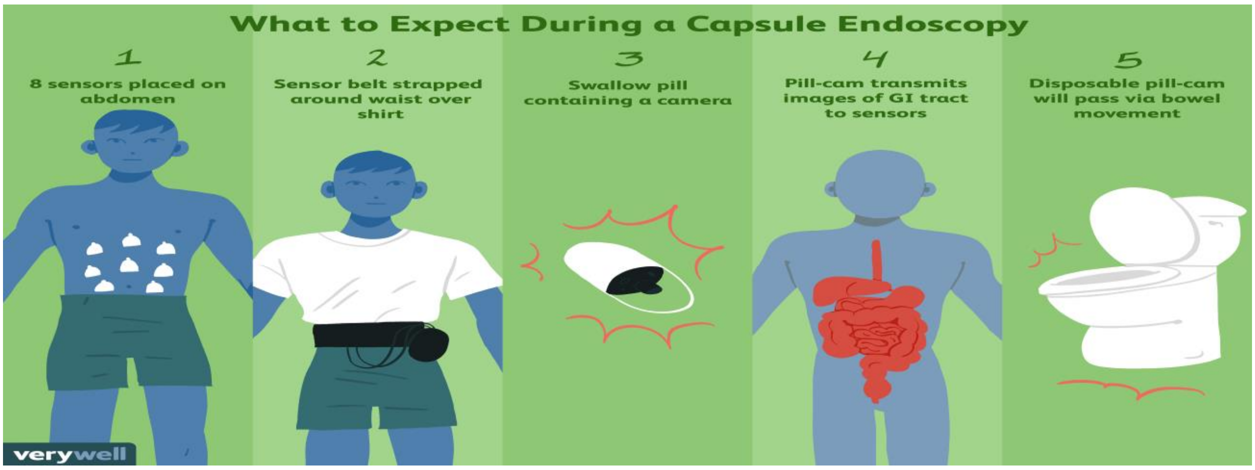

Fig.1 Applications of Capsule Endoscopy

II. APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN CAPSULE ENDOSCOPY

Since the latter part of the year 2000, artificial intelligence (AI) has undergone significant development for the purpose of identifying abnormalities in the small bowel (SB) based on capsule endoscopy (CE) images. Initial investigations primarily focused on technical challenges, often employing support vector machine (SVM) or multilayer perceptron network as AI classifiers. Studies within the bio computational domain demonstrated favourable outcomes in detecting various conditions such as polyps/tumours, ulcers, celiac disease, hookworms, Angio ectasia, and bleeding. However, these studies were constrained by a limited pool of patient data, lacking comprehensive clinical information regarding inclusion and exclusion criteria. Hence, there is a pressing need for more robust evidence to validate the clinical applicability of proposed computer-aided diagnosis (CAD) systems from the bio computational field.

As deep learning algorithms have progressed, the convolutional neural network (CNN) has emerged as the predominant deep learning approach for image analysis. The CNN system excels in extracting specific features through convolutional and pooling layers, utilizing back-propagation to generate optimal feature maps. Remarkably, the CNN system has demonstrated exceptional performance in detecting or characterizing abnormalities in the oesophagus, stomach, and colorectal areas. This technology is actively under exploration for its potential integration with capsule endoscopy in clinical settings.

III. ROLE OF ARTIFICIAL INTELLIGENCE IN CAPSULE ENDOSCOPY

The convergence of expansive medical datasets and the ongoing progress in computer technology has catalyzed significant strides in the application of artificial intelligence (AI), particularly through deep learning, within the medical domain. A prominent arena of research is the development of computer-aided diagnosis (CAD) systems utilizing images from esophagogastroduodenoscopy (EGD) and colonoscopy, showcasing notable efficacy in the realm of gastroenterology. Typically, a capsule endoscopy (CE) video encompasses an average of 50,000-60,000 frames during a single examination, demanding a considerable reading time ranging from 30 to 120 minutes for physicians, contingent upon their level of expertise. The inherent challenge lies in the laborious and time-consuming nature of CE interpretation, as physicians meticulously review numerous images with unwavering focus. Furthermore, small bowel (SB) abnormalities might manifest in just a handful of frames within the video, exhibiting a diverse range of colors, shapes, and sizes. This underscores the potential for oversights during the manual reading process conducted by physicians.

Given the voluminous nature of CE images, the integration of AI into CE presents an appealing solution. It holds the promise of diminishing reading time and streamlining the identification of specific landmarks and potentially concerning abnormalities. A mounting body of evidence underscores the clinical significance of AI in the domain of capsule endoscopy.

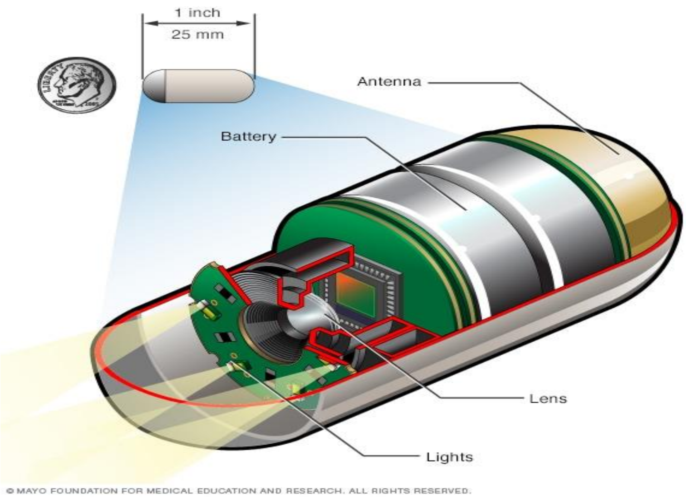

Fig.2 System Architecture of Capsule Endoscopy

IV. LITERATURE SURVEY

An extensive exploration of the existing body of literature reveals a burgeoning field in the application of artificial intelligence (AI) to capsule endoscopy. The synthesis of knowledge from diverse sources highlights the evolving landscape where cutting-edge technology intersects with medical diagnostics.

The literature survey encompasses a comprehensive review of studies and research endeavors, focusing on the integration of AI into the realm of capsule endoscopy. These investigations delve into the development, implementation, and outcomes of AI-based approaches, with a particular emphasis on enhancing the efficiency and accuracy of small bowel examinations.

Various scholarly works contribute to a nuanced understanding of the challenges and opportunities associated with employing AI in capsule endoscopy. From early studies utilizing support vector machines and multilayer perceptron networks to the more recent prominence of convolutional neural networks, the progression of AI algorithms is evident in tackling the intricate task of image analysis in the gastrointestinal context.

The survey also sheds light on the clinical implications of AI in capsule endoscopy, showcasing promising outcomes in the identification of abnormalities such as polyps, tumors, ulcers, and bleeding. Despite these advancements, the literature underscores the need for further robust evidence, emphasizing the importance of refining and validating AI systems for real-world clinical applications.

In essence, the literature survey provides a panoramic view of the dynamic landscape where artificial intelligence converges with capsule endoscopy, outlining the strides made, challenges encountered, and the promising avenues that lie ahead in the pursuit of more effective and efficient diagnostic methodologies.

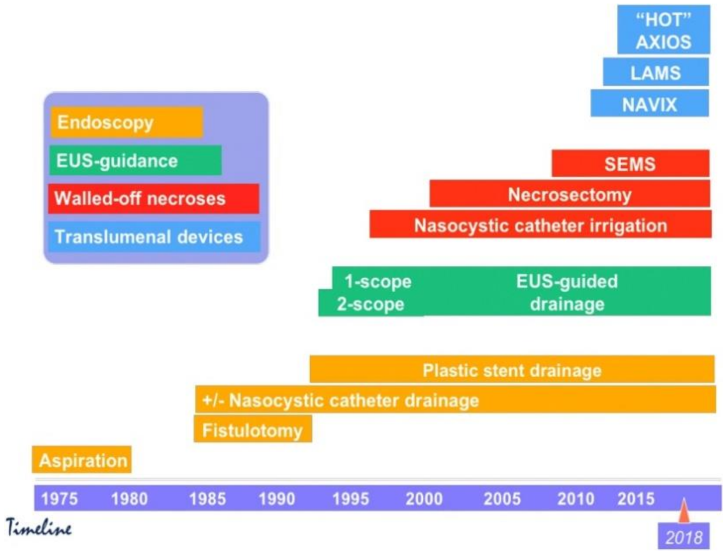

Fig.3 Evolution of Capsule Endoscopy

4.1 Capsule Endoscopy Technologies:

Capsule endoscopy technologies have evolved significantly since their inception in the early 2000s. These technologies aim to provide non-invasive and comprehensive visualization of the gastrointestinal tract, particularly the small bowel. Here are some key aspects and advancements in capsule endoscopy technologies:

1. Wireless Capsule Endoscopy (WCE):-

The hallmark of capsule endoscopy is its wireless nature. The patient swallows a small, pill-sized capsule containing a camera, light source, and transmitter. As the capsule moves through the digestive system, it captures images, which are wirelessly transmitted to a data recorder worn by the patient.

2. Camera Technology:

Advances in camera technology have led to improved image quality and resolution in newer capsule endoscopy systems. High- definition cameras enhance the clarity and detail of images, aiding in the detection of subtle abnormalities.

3. Battery Efficiency:

Enhancements in battery technology have extended the operational time of capsule endoscopes. Longer battery life allows for prolonged examination periods and increased coverage of the gastrointestinal tract.

4. Viewing Angle and Coverage:

Modern capsule endoscopes often feature a wide-angle lens, allowing for a broader field of view. Some capsules are designed to provide 360-degree panoramic images, ensuring comprehensive coverage of the intestinal walls.

5. Locomotion and Control:

Research is underway to develop capsules with locomotion capabilities. Magnetic or robotic systems are being explored to actively control the movement of the capsule, enabling targeted examination and navigation through the gastrointestinal tract.

6. Colon Capsule Endoscopy:

Capsule endoscopy has expanded beyond the small bowel to include the colon. Colon capsule endoscopy involves the ingestion of capsules that capture images as they traverse the colon, providing an alternative to traditional colonoscopy.

7. Artificial Intelligence (AI) Integration:

AI algorithms have been increasingly incorporated into capsule endoscopy interpretation. These algorithms aid in the automatic detection of abnormalities, reducing the time required for manual review and potentially improving diagnostic accuracy.

8. Biopsy and Therapeutic Capabilities:

Research is ongoing to develop capsules with biopsy capabilities, allowing for the collection of tissue samples during endoscopy. Additionally, there are investigations into capsules with therapeutic functionalities, such as drug delivery or interventions for certain gastrointestinal conditions.

9. Data Transmission and Connectivity:

Advances in data transmission technology enable real-time or near-real-time viewing of images during the capsule endoscopy procedure. Connectivity improvements facilitate seamless communication between the capsule and external devices.

V. CASE STUDIES (REAL WORLD IMPLEMENTING CAPSULE ENDOSCOPY)

Regarding the movement of the capsule, Fontana et al. innovatively designed a single-camera spherical capsule endoscope specifically for colorectal screening. The unique spherical shape was engineered to minimize friction during its traversal through the colon. Its locomotion was achieved through the interaction of the integrated permanent magnet with an external electromagnet, effectively actuating its movement. Fu et al. proposed an alternative approach with a magnetically actuated micro-robotic capsule, incorporating hybrid motion capabilities such as screw jet motion, paddling motion, and fin motion. This capsule relied on an electromagnetic actuation system generating both rotational and alternate magnetic fields to propel its motion. Guo et al. introduced a spiral robotic capsule guided by an external magnetic field. This capsule, featuring a modular structure with a guided robot and an auxiliary robot, moved relative to each other under the influence of the same external magnetic field. This design streamlined navigation to target lesions, reducing the time required for the procedure.

In the realm of capsule endoscopy with biopsy capabilities, various initiatives have emerged. Micro-jaw forceps and two magnetic-based robotic devices, the centimetre-scaled untethered magnetically actuated soft capsule endoscope (MASCE) and the submillimetre-scale self-folding micro gripper, have been explored. Notably, Son et al. developed B-MASCE, facilitating fine-needle aspiration biopsy with axial jabbing motion and rolling locomotion for biopsy in the stomach. The control and torque of the magnet within the capsule were manipulated using a magnetic field, and four soft legs guided the penetration of the needle into the target lesion.

Beyond diagnostic capsules, researchers have proposed therapeutic capsule prototypes. Stewart et al. introduced Sono CAIT, a capsule designed for ultrasound (US)-mediated targeted drug delivery. This innovative capsule integrated a US transducer, drug delivery channel, vision module, and a multichannel external tether. The capsule employed US to release drugs and enhance drug uptake via suboperation at the target lesion. Leung et al. developed a capsule for hemostasis utilizing an inflated balloon. Comprising a gas generation chamber, an acid injector, and a circuit hose with flexible joints, this capsule achieved hemostasis by inflating the balloon through acid injection into a gas generation chamber filled with phase powder, providing tamponade at the bleeding site.

VI. FUTURE TRENDS

Despite the remarkable achievements observed in numerous research groups exploring the application of artificial intelligence (AI) in capsule endoscopy (CE), the transition of AI into real-world patient management beyond the confines of clinical studies has not yet materialized. Several formidable challenges must be surmounted to pave the way for the clinical implementation of AI in this context.

Primarily, most published studies thus far have been retrospective in nature, relying on data from a single centre or a limited number of centres. This approach introduces inherent biases, such as selection and spectrum bias, limiting the generalizability of established convolutional neural network (CNN) systems. The efficacy of AI systems, particularly CNN, is contingent on robust training data, emphasizing the necessity for high-quality data in model development. Moreover, the opacity of the AI system's mechanism (referred to as a "black box" with limited interpretability) underscores the importance of rigorous validation to assess its performance. Studies lacking prospective or external validation run the risk of overfitting, where the learning model is overly tailored to the specific training dataset, hindering its ability to predict future observations. Therefore, comprehensive evaluation through multicentre, prospective studies and external validation using diverse datasets unrelated to model development is imperative.

Secondly, in many studies, CNN systems were trained and validated using static CE images rather than dynamic videos. The preference for clear and accurate images over inadequately prepared ones, fraught with bubbles, debris, and bile, adds another layer of complexity. Factors such as light limitations, low resolution (320×320 pixels), and diverse orientations of small bowel lesions arising from free mobilization pose challenges to the robustness of AI applications.

Furthermore, unresolved issues persist for the clinical application of AI in CE, extending to its integration into other medical fields. Prior to widespread incorporation into community practice, demonstrating cost-effectiveness and ensuring the satisfaction of both patients and physicians are paramount. It is envisioned that AI systems will serve as supplements rather than replacements in the medical field. Consequently, establishing educational frameworks for physicians regarding AI implementation and fostering an understanding of the technology becomes essential. Legal and ethical considerations surrounding the responsibility of AI application and significant reimbursement concerns demand attention.

Finally, the potential deterioration of CE image quality in real-world practice adds a layer of uncertainty. The performance of established CNN systems cannot be guaranteed in actual clinical settings. Thirdly, as different CE systems exhibit distinct image processing characteristics, the applicability of established CNN systems across various CE platforms is questionable. Hence, embracing diverse CE systems and incorporating data from a wide array of clinical scenarios becomes pivotal for the clinical deployment of evolving CNN systems.

VII. CONCLUSIONS

With its rapid advancement, capsule endoscopy (CE) has emerged as a crucial diagnostic tool for investigating conditions such as obscure gastrointestinal bleeding, Crohn's disease, small bowel tumors, and polyposis syndrome. However, the hindrances posed by the time-consuming and labor-intensive reading process, coupled with the absence of active locomotion, pose significant challenges to the widespread adoption of CE in clinical practice. In this review, we delve into recent convolutional neural network (CNN)-based methodologies applied to capsule endoscopy, specifically targeting the detection of diverse small bowel abnormalities, including erosion/ulcers, angioectasias, blood content, and protruding lesions. While the existing body of literature demonstrates the promising diagnostic accuracy of CNN systems, several hurdles must be surmounted for their seamless integration into real-world clinical practice. Rigorous multicenter, prospective studies, coupled with external validation, are essential to furnish robust evidence attesting to the CNN system's performance in capsule endoscopy. Moreover, in the context of colonic examinations, magnetically guided capsule endoscopy has demonstrated potential as a viable alternative to traditional endoscopy. Ongoing advancements in capsule endoscopy technology, focusing on active locomotion, image enhancement, and therapeutic capabilities, are under active investigation. These innovations hold the promise of being seamlessly integrated into patient management protocols in the foreseeable future.

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