Chapter 1

IoT-Based Intelligent Capsule Endoscopy System: A Technical Review

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Chapter Outline

1.1 INTRODUCTION

Wired endoscopy systems have been widely used to diagnose and monitor abnormalities in the gastrointestinal (GI) tract, such as obscure GI bleeding, Crohn's disease, cancer, and celiac disease [1,2]. Although effective and reliable, traditional endoscopy may cause discomfort and introduce complications in patients as this process requires a long and flexible tube to be pushed into the GI tract [3]. In addition, it is difficult to monitor certain

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areas of the GI tract, such as the largest part of the small intestine [4]. Also, these endoscopes need trained professionals to operate them, which further requires a long time [5]. As a result of technological progress and successful clinical demonstrations, completely noninvasive endoscopic systems requiring no sedation have become a reality and are now commercially available for the diagnosis of various GI disorders.

A typical wireless capsule endoscopy (WCE) system consists of a pill-shaped electronic capsule, sensor belt, data recorder, and a workstation computer with image-processing software, as illustrated in Fig. 1.1. This electronic capsule is integrated with an image sensor, illumination optics, processing unit, communication modules, and batteries. The main features of various commercially available capsules are summarized in Table 1.1. It is clear from the table that image, sensor-based capsules are more abundant in the market. Other capsules utilize different sensors, such as a temperature sensor, pH sensor, or pressure sensor, to measure different physiological parameters. Although, the capsule endoscopy system has gained much popularity and shown its effectiveness, there are still significant limitations as evident from Table 1.1. The major limitations are lower battery-life, suboptimal image quality, lack of localization, and active locomotion control.

Integration of different sensors with the emerging Internet of Things (IoT) technology may enhance the existing functionality to a greater extent. Fig. 1.2 categorizes the additional features that can be introduced in the WCE system with the help of IoT based WCE system in the future. Each of these functionalities is discussed in detail in the following sections.

The remainder of this chapter is organized into four sections. Section 1.2 presents the data acquisition system, while Sections 1.3, 1.4, and 1.5 discusses the processing unit, data management, and proposed IoT-based WCE system, respectively.

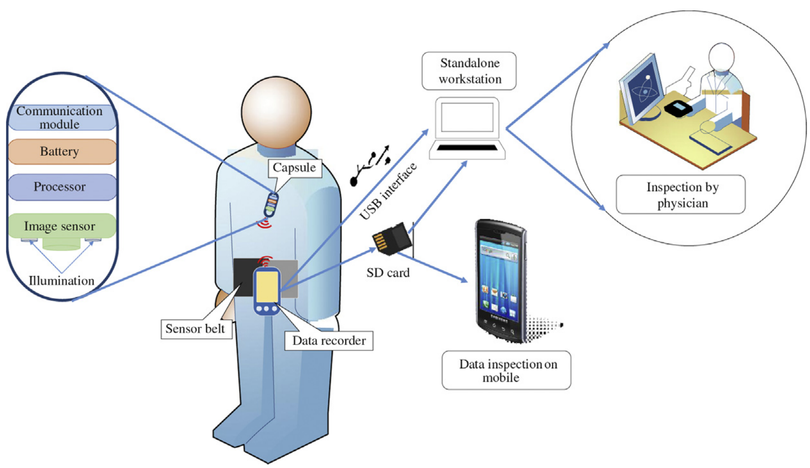

FIGURE 1.1 A typical block diagram of a wireless capsule endoscopy.

TABLE 1.1 Main Features of Commercially Available WCE Capsules

WCE Capsules Based on Image Sensor												
Device	**Company**	**Target Region**	**Size (mm)**	**Mass (g)**	**IL (LEDs)**	**BL (h)**	**FoV (°)**	**FR**	**Image Sensor**	**Res.**	**TM**	**RT**
PillCam SB	Given imaging/ medtronic	Small bowel	26×11	< 4	6	8	140	2	1 CMOS	256×256	RF	Yes
PillCam SB2		Small bowel	26×11	2.9	4	8	156	2 or 4	1 CMOS	256×256	RF	Yes
PillCam SB3		Small bowel	26×11	3	4	12	156	2 or 2–6	1 CMOS	256×256	RF	Yes
PillCam ESO		Esophagus	26×11	2.9	6	0.5	172	35	2 CMOS	256×256	RF	Yes
PillCam ESO2		Esophagus	26×11	2.9	2×4	0.5	169	18	2 CMOS	256×256	RF	Yes
PillCam Colon		Colon	31×11	2.9	2×6	10	172	4	2 CMOS	256×256	RF	Yes
PillCam Colon2		Colon	31×11	2.9 ± 1	2×4	10	360	4–35	2 CMOS	256×256	RF	Yes
Miro Cam	Intromedic	Small bowel	24.5×10.8	3.25	6	12	170	3	1 CMOS	320×320	HBC	Yes
Endo Capsule	Olympus	Small bowel	26×11	3.3	6	12	160	2	1 CCD	1920×1080	RF	Yes
OMOM	JinShan	Small bowel	27.9×13	≤ 6	4	8 ± 1	140 ± 10	0.5 or 2	1 CMOS	640×480	RF	Yes
Capso Cam	Capso Vision	Small bowel	31×11	4	16	~ 15	360	3 or 5 p.c	4 CMOS	1920×1080	USB	No

WCE Capsule Based on Other Sensors								
Device	**Company**	**Target Region**	**Size (mm)**	**Mass (g)**	**BL (h)**	**Sensor(s)**	**Measuring Parameter**	**TM**
SmartPill	Given Imaging/ Medtronic	GI tract	11.7 × 26.8	4.5	120	Pressure (0–350 mmHg), pH (0.05–9) and temperature (25–49°C)	Pressure, pH and temperature	RF
CorTemp	HQ Inc.	GI tract	10.37 × 22.32	2.75	168–240	Temperature sensor (30–45°C)	Temperature	RF
VitalSense	Philips	GI tract	8.7 × 23	1.6	240	Jonah™ core temperature sensors (25°C–60°C)	Core body temperature, dermal temperature, heart rate, respiration rate	RF
e-Celsius	BMedical Pty Ltd	GI tract	8.9 × 17.7	1.7	480	Temperature sensor (25°C–45°C)	Core body temperature	RF
Check-Cap	Check Cap Ltd	Colo-rectal	34 × 11.5	–	–	X-ray based 3D imaging	3-Dimensional lining of colon	RF

FoV: field of view; FR: frame rate; Res.: resolution; TM: transmission module; RT: real time, p.c: per camera; RF: radiofrequency; HBC: human body communication; IL: illumination; BL: battery life.

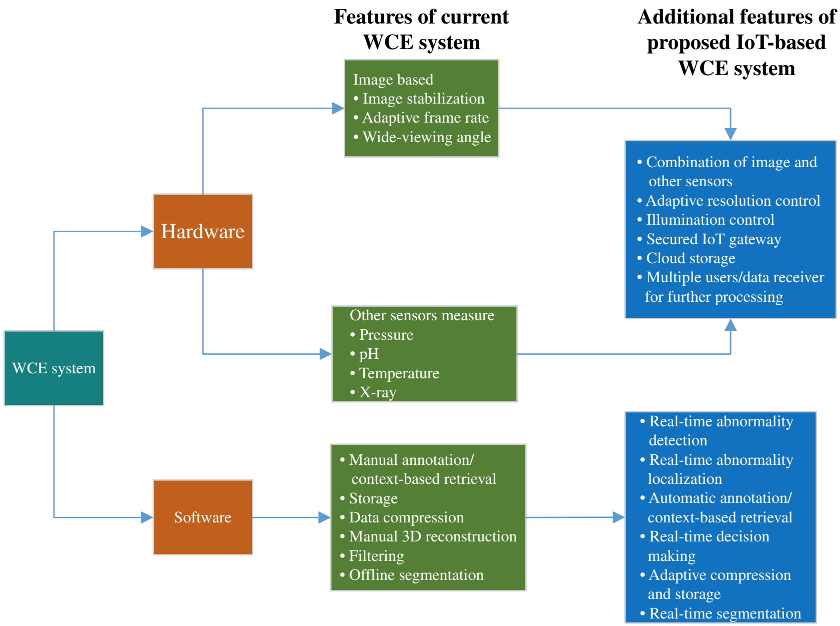

FIGURE 1.2 Comparison between current and the proposed IoT-based WCE system.

1.2 DATA ACQUISITION

Data acquisition in capsule endoscopy is performed using sensors. Since, the system is image-based, an image sensor is the main component. However, other sensors such as pH, temperature, pressure, and motion sensors have also been used. Usually, the outputs from sensors are analyzed, and actions are taken based on the analysis [6].

Determination of the GI motility, stricture, and produced gas in different regions of the GI tract could be used to diagnose various abnormalities. Moreover, ultrasonic reflection from the GI wall can provide detailed information about each layer, such as mucosa and submucosa. Besides these, the localization of abnormalities is an important issue which is still being researched. Various types of sensors could be utilized to address these issues which are discussed further in the following sub-sections. Fig. 1.3 shows some capsules that are available commercially.

1.2.1 Image Sensor

Conventional endoscopy systems use an image sensor to capture images of the GI tract. The image sensor (camera) along with illumination, processor, and wireless communication is miniaturized into a capsule. The most popular image sensor is the complementary metal oxide semiconductor (CMOS)

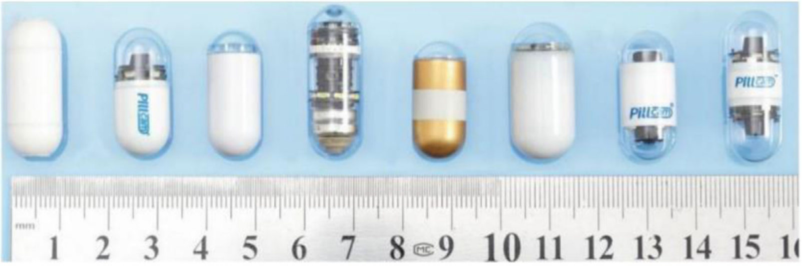

FIGURE 1.3 Commercial capsule endoscopes. Left to right: Agile patency capsule, PillCam SB2, EndoCapsule, CapsoCam, MiroCam, OMOM capsule, PillCam ESO, and PillCam COLON2 [81].

image sensor as it is cheaper, smaller, and consumes less power than charge-coupled device (CCD) image sensor. On the other hand, CCD image sensors offer a high quality and low-noise image [9]. Among the few small-bowel capsule endoscope models available on the market, PillCam, MiroCam, OMOM, and CapsoCam use CMOS imagers whereas the EndoCapsule uses a CCD imager [10].

1.2.2 Optical Sensor

The optical sensor measures different optical properties such as reflection, transmission, scattering, and absorption. The HemoPill includes an optical sensor that measures the intensity of transmitted light through a sample. The transmitted intensities of red and violet light are compared to detect acute bleeding [11,12]. The RGB color sensor can also be used to detect bleeding [13,14].

1.2.3 Pressure, Temperature, and pH-Monitoring Sensor

These sensors are used for motility monitoring. For instance, a pH profile can be useful to measure the transit time of the capsule. SmartPill (Fig. 1.3B) comprises all three sensors [15,16]. The temperature sensor is used in a few commercial capsules, such as, CorTemp [17], VitalSense [18], and e-celsius [19,20].

1.2.4 Other Ingestible Sensors

The odometer is a sensor that can measure the traveled distance of the capsule. OdoCapsule (Fig. 1.3C) uses this sensor to improve lesion localization [7,21]. Magnetic sensors could also be used to localize the capsule in real-time [22]. Ultrasound imaging in capsule endoscopy can be used to determine GI diseases. An ultrasound sensor emits ultrasound and reads the reflected sound from the GI wall. Mucosa, submucosa, and other layers of the GI wall have their own ultrasound profiles at normal states. However, abnormal profiles in any of the layers provide information about different types of diseases, such as tumors and cancer [23–26]. A gas sensor is used to get information about the chemical composition of the gut. A capsule has been developed by RMIT University, Australia that can sense oxygen, hydrogen, and carbon dioxide in the gut (Fig. 1.3D). This capsule could be used to evaluate the intestinal transit time, fermentative patterns, food modulation, drug disposition, intestinal physiology, and the effects of diet and medical supplements [8,27]. Radiofrequency identification (RFID) sends out an electronic signal which is detected by an external RFID scanner. The capsule can be localized using the RFID sensor. This sensor is used in the capsule to detect any stricture inside the GI tract to minimize the risk of occlusion. The patency capsule (Fig. 1.3A) uses a RFID sensor [28].

1.3 ON-CHIP DATA-PROCESSING UNIT

The acquired data from the sensors are processed by an on-chip data processor. A typical processing unit of a WCE capsule based on an image sensor is illustrated in Fig. 1.4. The required data is compressed and processed within the processing unit and later sent to the data recorder through the RF channel. The image sensor data can be compressed using different compression algorithms.

1.3.1 Image Compression

For detailed diagnosis and examination of the digestive diseases inside the GI tract, higher image resolution and frame rate are desired [34,35]. This will eventually increase the bit rate and power consumption of the RF transmitter. Therefore, efficient image compression techniques are required to compress the data, while maintaining an acceptable reconstruction quality of the source image. In a recent review [36], Alam et al. summarized the existing compression algorithms for WCE and also suggested some new techniques that can be used for future applications.

Turcza and Duplaga, in 2007 [37], proposed an image compression technique based on an integer version of discrete cosine transform (DCT) and the Huffman entropy encoder, which can produce both lossless and high-quality lossy compression. It is also suitable for simpler hardware implementation with limited power consumption. In 2006 [38], Lin et al. developed a

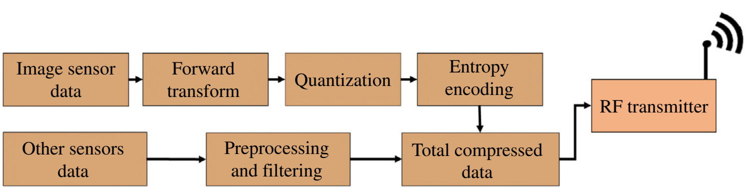

FIGURE 1.4 A typical processing unit.

low-powered, video compressor for GICam which consumes 14.92 mW and reduced the video size by a minimum of 75% and achieved RF transmission rate of 2 Mbps using the simplified traditional video compression algorithms with Lempel–Ziv (LZ) entropy coding [39] and a scalable compression architecture. Khan and Wahid [40] proposed an image compression algorithm based on a static prediction scheme and combination of golomb-rice and unary encoding with a compression ratio close to 73%. It requires lower computational complexity and 18 μW of power while working at 2 fps.

It can be seen that there exists a number of data compression techniques. The image compression algorithm in the capsule must consume a minimal amount of power to facilitate imaging of the entire GI tract. For this reason, a lossy image compression algorithm is usually selected to maintain a trade-off between the image quality and the frame rate, while minimizing the required physical size of the microchip and its power consumption.

1.3.2 Application Specific Integrated Circuit Design

For the proper implementation of image compression algorithms, as well as efficient processing of the various sensor data inside the capsule, the Application Specific Integrated Circuit (ASIC) chip plays a vital role. It also controls the transmission of the image sensor data using an RF channel and can take command of the RF channel to take action accordingly using a bidirectional communication method [41]. Predominant enhancement in the ASIC configuration can reduce the power utilization of the system and increase the frame rate of the image sensor. This chip was initially designed by Zarlink Semiconductor, Inc.

A low-power, near-field transmitter for capsule endoscopy was developed by Thone et al. [42]. They designed a low-power, near-field transmitter for the WCE system at 144 MHz carrier frequency to minimize the attenuation loss and to reduce power consumption to only 2 mW for transmitting the compressed image data at the rate of 2 Mbps. The antenna system size can also be reduced to a greater extent by using a high-frequency carrier. Goa et al. reduced the antenna size further with an ultra-wideband (UWB) (3–5 GHz), low-power telemetry transceiver system with a 0.18 μm CMOS process of 4×3 mm^2 outer dimensions and transmitted the image data at a rate of 10 Mbps with a 1.8 V power supply [43,44]. Diao et al. further improved the design by increasing the data rate to 15 Mbps at 900 MHz using an industrial, scientific and medical (ISM) band [45]. Later, Kim et al. designed a high-efficiency transceiver system of 0.13 μm CMOS process in 1.0 mm^2 silicon area with a simple on–off key transmitter having a data rate of 20 Mbps using a 500 MHz RF channel [46].

Integrated chips handle the image compression algorithms to increase the frame rate using the existing low data-rate transmission line. Khan and Wahid proposed a low-power, low-complexity compressor for capsule

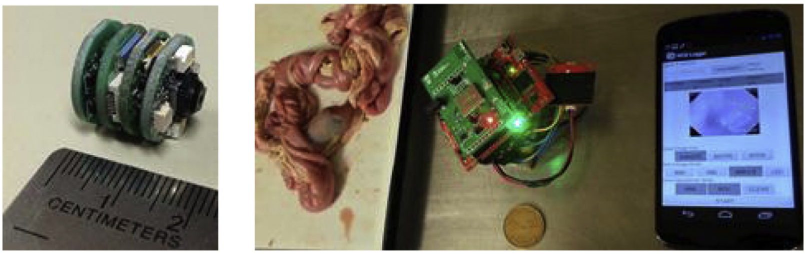

FIGURE 1.5 Prototype of an FPGA-based capsule with smart-device connectivity [47].

endoscopy [40] which can achieve a compression ratio of 80% using only 42 μW consumption power. Fig. 1.5 shows a prototype of an FPGA-based capsule with smart-device connectivity.

1.3.3 Radiofrequency Transmission

After processing and compressing the image sensor data, it is sent to the data logger using an RF transmitter. The receiver/recorder unit receives and records the images through an antenna array consisting of several leads that are connected by wires to the recording unit, which is worn in standard locations over the abdomen suitable for lead placement. The recording device to which the leads are attached is capable of recording images which are transmitted by the capsule and received by the antenna array. Considering the human body as a lossy dielectric media that absorbs the waves and attenuates the receiving signal, it presents a strong negative effect to the microwave propagation. Hence, the quality of the received images and the power consumption of the battery depend on the signal-transmission efficiency of the antenna [48].

The role of the embedded antenna is to transmit the detected signals from inside the body to the receiver outside the human body. The ideal antenna for WCE should be less sensitive to human tissue and must have enough bandwidth to transmit high-resolution images along with a high-data rate [48]. Spiral, double-arm spiral, conical helix, fat-arm spiral, square microstrip loop, etc., are the types of antennas which are generally used in commercial WCE as well as in research [48]. A spiral transmitting and receiving antenna is shown in Fig. 1.6.

The mode of data transmission currently uses ultra-high frequency (UHF) band radio telemetry (e.g., PillCam, EndoCapsule). The human body communications (HBC) used by MiroCam is another type of transmission mode that utilizes the capsule itself to generate an electrical field that uses human tissue as the conductor for data transmission [50]. Inductive, link-based designs typically use a frequency transmission of 20 MHz or lower [51].

Using low frequency can achieve high transmission efficiency through layers of human skin [50]. The 402 MHz (UHF) Medical Implant Communication Service is a global, license-free service that has a small

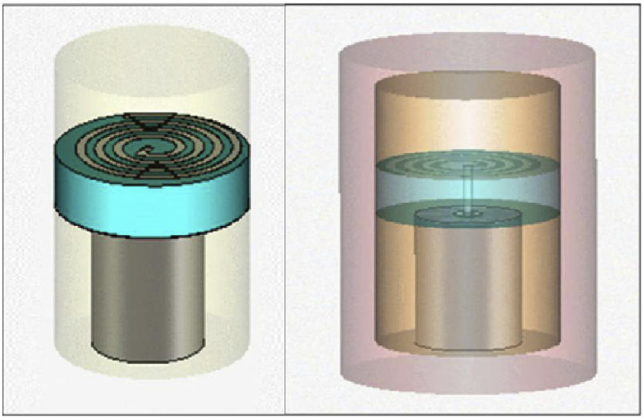

FIGURE 1.6 Spiral transmitting and receiving antenna [49].

bandwidth of 300 kHz, which is insufficient for video imaging-based WCE application as they require high-data rate and high resolution. The 2.45 GHz ISM band, on the other hand, offers a larger bandwidth [52] although this is still not enough due to impedance mismatch in a wide bandwidth. One of the possible frequency bands to provide high-resolution images from WCE is the use of UWB at the frequency of 3.1–10.6 GHz [53]. Hence, the selection of a proper operating frequency and transmission channel has received significant attention in current research. The different modulation techniques that have been used in RF telemetry are Frequency Shift Keying, Amplitude Modulation, On–Off keying, and Binary Phase Shift Keying, etc. [51] IEEE C95.1–2005 is the human exposure standard in RF radiation. It stands for Standard for Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 3 kHz to 300 GHz.

1.3.4 Power Management

The power management unit mainly consists of processing logic and power sources, such as batteries. Frame rate modulation techniques can also be used to control the frame rate within the desired area to ensure the capsule's longer operating time [54]. Smart Motion Sense Technology can also be helpful to activate or deactivate the capsule camera by sensing the motion within the GI tract [55]. Synchronous switching of the light-emitting diode (LED) and the CMOS sensors can also minimize power consumption. An intelligent energy efficient system was proposed by Liu et al., which can shut down and wake up necessary components of the capsule when needed [56].

Moreover, there will be many other sensors along with the image sensor to provide additional functionalities, like bleeding detection, active system control over the capsule's motion, gas sensing, active locomotion, and localization etc., in the more-advanced IoT-based WCE system. However, these will require much more power which may not be fulfilled by a conventional power source that can merely deliver around 25 mW [57,58]. Harvesting energy from different ambient sources, such as radiofrequency, light, vibrations, or thermoelectricity, can provide electrical energy in the range of μW, which is still very low for a WCE system [59]. Therefore, wireless power transmission (WPT) may be the best alternative to overcome the power limitations of an onboard battery system. In case of WPT, a transmitting coil is kept at a certain distance and appropriate location outside the human body and the receiving coil is placed within the WCE. The WPT was first tested by RF System Lab on their capsules (Norika and Sayaka) which did not need any battery power [60]. One group has proposed primary magnetic coils in a power-generating device outside the body to send power to a capsule within the body to save space [61]. Lenaerts and Puers introduced an inductive power link which was capable of transmitting 150 mW [62]. Recent research on WPT has improved significantly and can easily transmit 500 mW of power [63]. The WPT also offers the flexibility of adjusting the required amount of power for the capsule. Hence, it could be said that the WPT would be the best option to provide relatively higher levels of power to an active WCE system with multiple sensors.

1.4 DATA MANAGEMENT OF WIRELESS CAPSULE ENDOSCOPY SYSTEMS

The WCE system still relies greatly on workstation software. A typical endoscopy capsule, when administered into the human body, works for about 8–10 h and generates around 57,600 frames [64]. A doctor/physician is still required to sit in front of the computer to analyze each frame which is tiresome and inefficient. Although some functionalities exist that help the physician for automating the detection of abnormalities, the existing features are still inefficient and unreliable. During postprocessing, the data recorded on the data logger is retrieved at a workstation where software is installed to analyze the recorded data. This software is provided by the corresponding vendor. Different vendors of WCE have developed various software with different functionalities which are maintained and updated regularly, for example, RAPID Reader software is developed and provided by PillCam.

This software includes some advanced functionalities that help physicians with automating detection of bleeding. In particular, the suspected blood indicator helps in distinguishing red pixels of the captured images by image sensor automatically. The sensitivity for identification of active bleeding is reported to be in the range of 58.3%–93% [65,66]. These results reveal that this software cannot replace physicians; however, these additional features can definitely help physicians to detect bleeding inside the GI tract and save time.

Many researchers have been working on automating the detection of abnormalities inside the GI tract during postprocessing. Li et al. [67] proposed the novel idea of chrominance as a part of the color texture feature, which utilizes Tchebichef polynomials and an illumination invariant of Hue/Saturation/Intensity color space which is used to differentiate between normal and bleeding regions. Similarly, Pan et al. [68] proposed a computer-aided system based on a neural network where color texture features of bleeding regions are extracted and a probabilistic classifier is built to detect bleeding.

1.5 IOT-BASED WIRELESS CAPSULE ENDOSCOPY SYSTEM

With a view to provide better patient care, reduced health service cost, and improved treatment outcomes, IoT is constantly offering new opportunities to enhance the integrated health-care field either by introducing new scopes of health-care facilities or by improving existing systems of health care [71]. Current common hospital-centered health care will be transformed from, first to hospital-home-balanced care by 2020, and ultimately, to home-centered care by 2030 [72]. The current WCE system cannot yet offer real-time detection as the diagnosis is done offline. In addition, a self data-analyzing intelligent system could be helpful, which can select useful data for transmission and save transmission cost, bandwidth, and energy. Real-time viewing may also assist in capsule manipulation and drug delivery in the future [73]. To develop IoT-based systems, characteristics like intelligence, heterogeneous network connectivity, real-time sensing capability, and security may be incorporated into the system.

1.5.1 Intelligence in the System

Intelligent decision-making capability is a built-in key utility factor of any IoT-associated system [74]. Current research shows that intelligent features, such as the adaptive frame rate and the wide viewing angle, can be implemented in the capsule when used in real-time [75]. An IoT-based system can make instant decisions by making a choice between useful and redundant frames. Besides, it can efficiently detect selected anomalies inside the GI tract based on predefined algorithms.

1.5.2 Real-Time Sensing

The instant decision-making capability of the system requires real-time sensing abilities that an IoT-based system can offer [63,74]. Real-time monitoring allows physicians to take quick measures when required. Besides, with the advent of real-time viewing and external manipulation, the notion of targeted drug delivery (targeted therapeutics) becomes feasible [76]. Capsule propulsion needs to be followed by real-time viewing during the first hour to make sure the capsule passes the stomach [55].

1.5.3 Internet of Things Protocol

Compared to the traditional networking protocols, the dedicated IoT protocols are lightweight in nature, consume less bandwidth, less power (Message Queuing Telemetry Transport (MQTT) and Constrained Application Protocol (CoAP) are familiar as constrained application protocols). Hence, IoT communication protocols are best-suited for low power, constraint environment devices like WCE to transfer various sensor data in real time. Besides this, IoT protocols offer bidirectional control over sensors [77]. For example, the resolution or frame rate may be adjusted for diagnostically important frames.

1.5.4 Connectivity

IoT devices may support several interoperable communication protocols (for example CoAP can interoperate with Hyper Text Transfer Protocol (HTTP) [77]) and can communicate with other devices and infrastructure [74]. It also provides less, or no, latency in communication. In fact, the smart IoT gateways can act as a hub between wireless body/personal/local area networks (WBAN/WPAN/WLAN) and a remote health-care center [78]. This feature can successfully integrate remote monitoring of the endoscopy capsule so that the data acquired can be accessed by qualified physicians from anywhere in the world.

1.5.5 Security

Ensuring the confidentiality and privacy of medical images is becoming a challenging problem as these images contain sensitive data with distinguishing visual representations of the interior of a human body [71]. Current research shows that it is possible that this image data can be transferred through Wi-Fi remotely using a smartphone as the workstation [79]. Therefore, it is necessary to send the frames securely. An IoT-based system provides functions such as authentication, authorization, privacy, message integrity, content integrity, and data security [74]. For example, MQTT uses Transport Layer Security/Secure Sockets Layer (TLS/SSL) and CoAP uses Data-gram Transport Layer Security (DTLS) for security [77].

1.5.6 Improved Outcomes of Treatment

The automatic connectivity through cloud computing or another virtual infrastructure gives physicians the ability to access real-time information that enables them to make informed decisions. This ensures improved health care and treatment outcomes through reduced human contact with patients [80].

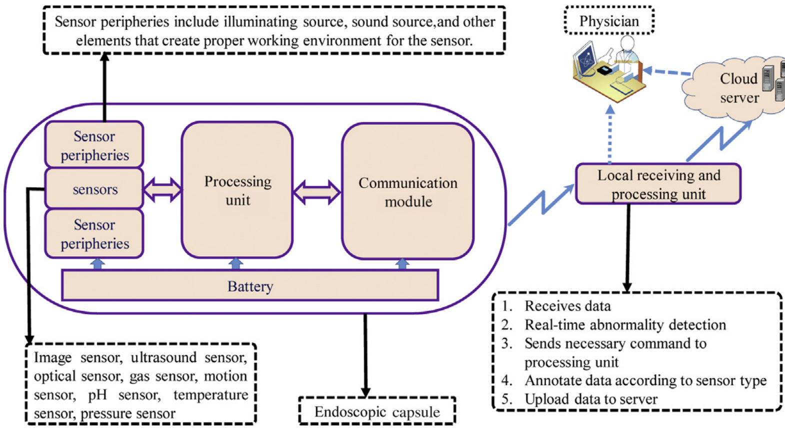

FIGURE 1.7 Proposed IoT-based future WCE system.

The proposed IoT-based WCE system is illustrated in Fig. 1.7. The system connects the body sensor network that consists of multiple sensors as described in Section 1.2. The sensor peripheries will help to create a proper working environment for the corresponding sensor, for example, an image sensor requires an illumination source (LED), and an ultrasound sensor may require a sound source, etc. The sensor data will be processed with the help of the processing unit which will be transmitted with the help of the communication module to the local processing and receiving unit that consists of the IoT gateway and local processing unit outside the body. The communication module can be a bidirectional RF transceiver. The IoT local processing unit can analyze and annotate different types of sensor data according to the abnormality. It can also send commands to the processing unit inside the capsule, for example, when an abnormality is detected in an image, it can send a command to increase the frame rate, resolution, or illumination, etc. By extracting the information and sorting them, the IoT gateway can further proceed these data toward the remote area network using IoT protocols like MQTT or CoAP, etc., with the built-in security (like DTLS or TLS). The receiver of these data can be a dedicated WCE cloud server from which an authorized physician can access the data in real-time from anywhere by using either PC, phone, or website. The WCE cloud server will store all data of the corresponding patient for further use. Finally, the intelligence of IoT can efficiently accelerate detection and help physicians to receive the necessary information to diagnose the actual disease type quickly.

1.6 FUTURE CHALLENGES

While some of these sensors are used in commercial pills, many new sensors can be integrated to improve the tool's effectiveness and diagnostic accuracy.

Localization is an important issue for the treatment of GI diseases. The pH and pressure profile of the human GI tract could be used to localize the capsule based on different GI profiles, such as when it leaves the stomach, duodenum, or jejunum. The motion sensor and RFID can also provide sufficient information about localization [29,30]. Optical sensors are able to determine bleeding and can be used to detect other abnormalities of the GI tract, such as the lesions, tumors, and cancerous cells [31,32]. Other imaging techniques, such as the ultrasound imaging, fluorescence imaging [33], and X-ray imaging could provide additional, in-depth information of the gut. Moreover, the possibility of missing the abnormalities by traditional technologies will be reduced by using multiple sensors. By using these sensors, it is also possible to prolong battery life to several days [27]. Future WCE software should have an additional feature to distinguish between normal and abnormal profiles.

Data management is necessary in order to efficiently gain the information that the user is looking for, either in a single video of a trial or in an archive. The software should be able to respond to a specific index-based query which lists the desired information. This will help with efficient content exploration.

The current scenario to retrieve information from a large video is to manually annotate each frame. However, manual annotation is not always a feasible option when there is a large video, especially if the physician has a limited time. Hence, it will be interesting to utilize the technique used by doctors to extract the important information from a limited number of frames and apply the same technique for the remaining video archives. The content-based, image-retrieval system will help in distinguishing between images of interest to those of no interest.

In terms of compression and storage, only the frames of interest can be compressed and stored. Munzer et al. [69] showed that the circular segment of the endoscopic images (which is usually dark, blurry, or noisy) can be discarded for improving encoding efficiency and saving 20% storage space. Lossless compression can be incorporated for the region of interest while lossy compression can be used for other regions [36]. Besides these, storing the videos in HD quality is not always required; in some cases a lower quality of images still provides enough clarity for subjective evaluation [70].

1.7 CONCLUSION

The objective of this chapter is to discuss the limitations of the current WCE system and suggest possible remedies. The WCE tool plays an important role in diagnosing GI tract disorders through a painless procedure. It is a safe procedure and widely used for small-bowel screening, where a wired endoscope cannot reach. However, the system lacks illumination and resolution control, localization of abnormality, and real-time decision-making, etc. Therefore, an improved WCE system is needed which must resolve the challenges of data acquisition, data storage and processing, and data analysis as major blocks. The data acquisition block consists of various sensors, such as image, gas, temperature, optical, ultrasound, pH, and motion sensors. These sensors aid in improving various functionalities of the current capsule endoscope, for instance by detecting and localizing abnormality inside the GI tract, real-time sensing, and increasing the quality of the images, etc.

The inclusion of an IoT platform will enable real-time diagnosis as well as adaptive illumination and resolution control. Analyzing data using the current capsule endoscopic system is another challenging task for a physician, as they are required to sit in front of a computer for 8−10 h to go through each frame. Although many image segmentations or auto-detection algorithms are already available, these features are offline. Thus a system which can automatically annotate the frames is needed which will help save time for physicians. It will also aid in saving storage space during postprocessing, as discussed in Section 1.4, making the system more efficient.

Considering the current limitations, it is essential that the IoT-based capsule endoscopy system is developed to improve the diagnostic efficiency of GI abnormalities. Improved imaging, adaptive resolution control, and an improved illumination source, as well as the development of novel tools for automating detection and the localization of abnormality, smart data management system utilizing IoT protocols are some of the important goals that need to be addressed in the development of future capsule endoscopy systems.

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