Wireless capsule gastrointestinal endoscopy: direction of arrival estimation based localization survey

Article

Accepted Version

Submission to IEEE Reviews in Biomedical Engineering

Methodological Reviews

Title: Wireless Capsule Gastrointestinal Endoscopy: Direction of Arrival Estimation based Localization Survey

Authors: Nilanjan Dey,

Amira S. Ashour,

Fuqian Shi, *Senior Member, IEEE*,

R. Simon Sherratt, *Fellow*, *IEEE*

Corresponding author: Amira S. Ashour, amirasashour@yahoo.com

N. Dey is with the Department of Information Technology, Techno India College of Technology, West Bengal, 740000, India (e-mail: neelanjan.dey@gmail.com).

A. S. Ashour is with the Department of Electronics and Electrical Communications Engineering, Faculty of Engineering, Tanta University, Egypt (e-mail: amirasashour@yahoo.com).

F. Shi is with the College of Information & Engineering, Wenzhou Medical University, Wenzhou, 325035, PR China (e-mail: sfq@wmu.edu.cn).

R. S. Sherratt is with the Department of Biomedical Engineering, the University of Reading, RG6 6AY, UK (e-mail: sherratt@ieee.org).

Abstract

One of the significant challenges in Capsule Endoscopy (CE) is to precisely determine the pathologies location. The localization process is primarily estimated using the received signal strength from sensors in the capsule system through its movement in the gastrointestinal (GI) tract. Consequently, the wireless capsule endoscope (WCE) system requires improvement to handle the lack of the capsule instantaneous localization information and to solve the relatively low transmission data rate challenges. Furthermore, the association between the capsule's transmitter position, capsule location, signal reduction and the capsule direction should be assessed. These measurements deliver significant information for the instantaneous capsule localization systems based on TOA (time of arrival) approach, PDOA (phase difference of arrival), RSS (received signal strength), electromagnetic, DOA (direction of arrival) and video tracking approaches are developed to locate the WCE precisely. The current article introduces the acquisition concept of the GI medical images using the endoscopy with a comprehensive description of the endoscopy system components. Capsule localization and tracking are considered to be the most important features of the WCE system, thus the current article emphasizes the most common localization systems generally, highlighting the DOA-based localization systems and discusses the required significant research challenges to be addressed.

Index Terms

Direction of arrival estimation, source localization, endoscopy, endoscopy capsule, endoscopy electronics, endoscopy equipment, medical sensors, wireless video gastrointestinal (GI) endoscopy capsule

I. INTRODUCTION

Endoscopy is a nonsurgical solid tube for visual examination of the digestion tract, for example the Colonoscopy and Gastroscopy can scope part of the Gastrointestinal (GI) tract. Patients feel very uncomfortable due to the long time of the endoscopy examination process. Additionally, several side effects can occur, such as intestinal wall perforation, breathing difficulty and infection during the inspection time [1]. Consequently, in order to avoid the traditional endoscopy drawbacks, Iddan *et al*. [2] presented Wireless Capsule Endoscopy (WCE) in order to diagnose GI conditions without the need for any sedation [3]. The WCE provides gains for both the physician and patient since it is precise, portable and noninvasive for the inspection of the human body's GI tract. The WCE is a capsule size medical device that captures internal images of the human intestine during its movement. It is equipped with a Radio Frequency (RF) transmitter, camera and a battery to transmit wirelessly the captured image to an exterior receiver that is placed outside the human body. WCE non-invasively assesses the entire small bowel with superior ability to detect the significant mucosal diseases, including polyps, ulcers and angiodysplasia compared to traditional endoscopy [4].

In order to link the captured images from certain region within the patient body with the WEC location, the localization processes becomes essential. Predominantly, in the WCE, the localization process depends on the emitted signal from the equipped sensors within the capsule and the detected signal strength through its movement in the GI tract. It is based on the labeled and identified images of the stomach entrance, the pylorus and the ileocecal valve. Typically, the localization process depends on the off-line processing of the Radio Frequency (RF) signal level of a sensor array placed outside of the body. However, since the digestive system is unpredictable and an extreme environment, several researchers are interested in developing WCE localization algorithms. Numerous WCE localization approaches have been proposed, including electromagnetic localization methods, RF localization techniques and the image-based localization as well as DOA-/TOA-based endoscopy capsule localization [5].

The electromagnetic localization techniques usually consist of magnetic axial sensors embedded in the capsule with attached energized coils to the patient's abdomen. The capsule's location/orientation are determined using the magnetic dipole data. Typically, optimal algorithms are employed to process the data from a number of sensors to provide high localization/positioning accuracy as well as orientation tracking [6]. The magnetic localization methods consist of permanent magnet-based localization and coil-based localization techniques. The coil-based technique is relatively insensitive to noise, however it requires external excitation. Instead, the permanent magnet based technique does not entail an exterior excitation. Thus, it is positioned in the WCE along with magnetic sensors located outside the human body to determine the magnetic field intensities created by the magnet in dissimilar spatial points. In addition, in the patient's body, image-based capsule localization techniques can be employed to localize the capsule position using image features. The image-based localization links the change in the features for any consecutive image pair to estimate the orientation/speed of the WCE [5]. The RF-based WCE localization requires an RF transmitter and associated antennas surrounding the human body. Processing the antenna signal determines the Received Signal Strength (RSS) along with a tracking procedure to define the capsule location in the body organs. Several techniques have been proposed for accurate capsule localization, where the exact capsule location is critical for the physicians in order to track the capsule motion and to know the capsule position related to the captured image [7].

The preceding localization techniques have some restrictions [5], including i) the magnetic-based localization requires a large number of sensor arrays to determine the WCE magnetic flux, and ii) the image quality, including the image distortion/resolution affects the image-based localization performance, where inadequate features and image distortion increases the localization error of the image-based approach. However, the RF signal based technique has several advantages, where it requires low-cost hardware for implementation and has application-non-specific properties. Typically, the classic RF signal based localization techniques estimate location-dependent signal parameters including the Angle of Arrival (AOA), Time of Arrival (TOA), or the RSS. Due to the signal reflections at the body organ boundaries, the common TOA/DOA based techniques do suffer from multipath conditions [7]. Consequently, there is a need to propose accurate DOA-based endoscopy capsule localization techniques.

Consequently, the present study has focused on WCE localization techniques. In addition, in the present work, an example of the WCE as a robotic endoscopic capsule is also demonstrated.

II. GASTROINTESTINAL MEDICAL IMAGE ACQUISITION USING ENDOSCOPY

The first wireless endoscopic system is the WCE that was launched in 2001 as a clinical product termed M2A by Given Image Ltd. The 11mm x 26mm M2A capsule is illustrated in Fig. 1 [6], where the M2A capsule components include the lens holder, optical dome, lens, Complementary metal–oxide–semiconductor (CMOS) imager; illuminate LEDs, battery, RF transmitter and the antenna. Initially, this active WCE is swallowed by the patient to start capturing photos through its movement in the GI tract. It passively traverses the food tract by ordinary peristaltic GI system movement until it reaches the colon. The captured images are relayed through the transmitter using an RF signal to the attached antenna array in the patient's body. Afterwards, this signal is conveyed to a data-recorder worn on a belt. Inside the patient's body, the position triangulation of the capsule is monitored by the sensor array so that the capsule path trajectory can be later presented on a monitor. The patient's examination initiates by attaching antennas to the chest of the patient to be coupled to the worn data-recorder. Immediately, the capsule acquires images though the RF transmission. Nevertheless, it takes long time for the capsule to go through the whole GI tract. Finally, the WCE is reflexively ejected from the human body.

Fig. 1.Capsule endoscopy [6]

However, this effective method suffers from relatively high power consumption of the camera and RF components, which leads to a limited 8-12 hours WCE lifetime to examine the small intestine and large intestine. Increasing functionality is a critical requirement for endoscopic system platforms. The image sensor and processing interpolation/engine systems are significant to achieve effective resolution. Typically, endoscopic system equipment necessitates increased processing performance, where image sensor technology develops higher resolution streams [8]. Furthermore, it is difficult to control the capsule's location/orientation, which may lead to missing the captured images of some spots [6]. In order to manage these limitations, a new wireless robotic capsule endoscope system can be employed to control the movement of the capsule externally.

III. ROBOTIC ENDOSCOPIC CAPSULES

WCEs can be passive (non-controlled) or active (controlled) locomotion. All active endoscopes use a wire to control the capsule movement and as a transmit medium for transmitting the captured images for external viewing. A new method of impelling the capsule using a magnetic accurator was proposed by Sendoh *et al*. [9]. In order to control the capsule movement, a permanent magnet was used with an external rotational magnetic field. In order to control the capsule locomotion, a new driving system was designed by Hu *et al*. [6], where a small permanent magnet was used. Furthermore, an orientation/localization system was compulsory for external locomotion of the capsule. A robotic capsule platform typically entails several modules, including vision, localization, locomotion, powering, telemetry and diagnosis/treatment tools.

A. Locomotion

Locomotion is a vital aspect of designing a robotic endoscopic capsule. The active locomotion implementation in an endoscopic swallowable capsule can follow one of the following strategies, namely embedding on-board internal locomotion system (miniaturized locomotion system) or using an external locomotion that relies on magnetic field sources [10]. The internal locomotion methods target the entire intestine, while the external locomotion methods use permanent electromagnets/magnets and involve external field sources to provide steering and navigation.

B. Localization

The capsule orientation/position is essential for localization of lesions in the GI tract by providing feedback for capsule motion to determine future follow-up treatment. Commercial WCEs employ several localization strategies on electric potential values or a single electromagnetic sensor coil. Spyrou *et al*. [11] designed a tracking technique based on image processing approaches using 3D reconstruction procedures based on consecutive frames registration. Numerous researchers have instead been motivated to propose localization approaches based on electromagnetic waves and magnetic fields. Typically, low-frequency magnetic signals can penetrate human tissue without attenuation; in addition the magnetic sensors do not necessitate the line of sight condition for detecting the capsule. However, the size of the required permanent magnet is limited by the capsule dimensions, which in turn limits the accuracy of the results. Numerous methods can be used in applications requiring active actuation systems. Kim *et al*. [12] employed magnets inside the WCE, where the capsule can be rotated by the force of an exterior rotating magnetic field. Inside the capsule, three hall-effect sensors were used to determine the capsule position/orientation. A localization system was recommended by Salerno *et al*. [13], which was compatible with the exterior magnetic locomotion using a triangulation procedure. A custom on–board tri–axial magnetic sensor was used for detecting the capsule in the GI tract. In addition, Salerno *et al*. established an online localization system by embedding a 3D accelerometer with pre-measured magnetic field maps and a 3D Hall sensor. Natali *et al*. [14] presented a localization algorithm, which was compatible with magnetic manipulation of the capsule by employing multiple sensors. In addition, the RF signal has been extensively employed to locate objects in both indoor and outdoor environments to attain high accuracy.

IV. WCE LOCALIZATION

Colonoscopy dominated the market for several years before the invention of WCE. It was considered the main procedure to conduct GI tract; however, it is unable to offer inspection inside the small intestine. Compared to the colonoscopy, WCE offers a comfortable, non-invasive and non-embarrassing method to inspect the patients' GI tract. The WCE device records images of any abnormalities inside the GI tract at a comparatively high rate to assist physicians diagnose and plan treatment. The WCE RF and visual localization accuracy is a critical issue, thus Zhou [15] attached two miniature cameras to the capsule in order to capture thousands of images during the capsule path through the GI tract. The captured images have a frame rate that varies from 2 to 8 frames/second to perform pseudo video. The most significant aspect of a WCE examination is to determine the accurate capsule position in order to recognize the detected intestinal abnormality/disease position. Consequently, several localization systems have been developed to precisely localize the WCE. The magnetic field methods, TOA-based methods, video-based methods, RSS-based techniques and the video-aided hybrid localization methods are different localization approaches. The RF localization possibility of the WCE has been discussed [16]. The localization of WCE using RF signals is particularly complex due to the complicated environment inside the human body. The RSS localization accuracy inside the human body has been previously considered [17] resulting in an average 50mm localization error in the human GI tract. In addition, the impact of the topology and the number of sensors on the localization accuracy need to be investigated further.

Moreover, researchers have been interested in TOA-based WCE localization. The foremost challenge for TOA-based localization of WCE is the mass of the human body. There are two directions in the TOA-based localization for heterogeneous tissue to find the signal trace and homogeneous tissue to conduct simulations. Furthermore, recently one of the evolving localization methods is the Phase Difference of Arrival (PDOA). Previously, for Body Area Network (BAN) localization, the PDOA has been considered as an inappropriate localization technique due to ambiguity. However, for in-body circumstances, the range between the transmitter and the receiver can be within several centimeters thus enhancing the opportunity of using PDOA.

V. WCE COMMUNICATION MODEL

The WCE communication system consists of a transmitter, a transmission channel and a receiver. In order to determine the WCE position, the electromagnetic wave propagation of the capsule communication channel through the human body can be employed [18, 19]. However, the small intestine near wall structure within the human body material influences the position localization results. Thus, in the human body model, optimally designed transmitting and receiving antennas are essential to for the communication system. Several studies have been conducted on the WCE system's antennas, such as the confocal antenna. These antennas are spaced inside the capsule for powerful batteries and more devices. Thus, the antennas can be attached or printed on the external or internal capsule surfaces' shell. However, the antenna's frequency detuning is required due to the effect of human body materials. In addition, the spiral antennas can provide a large border for the frequency shifting due to human organs' different material properties. Thus, the spiral antenna can be used in the capsule design [20-22]. Consequently, a spiral antenna can be used in the WEC transmitter using its advantages of low profile, omnidirectional radiation pattern, and small size.

VI. IMAGE-BASED CAPSULE LOCALIZATION

Due to the development of image processing algorithms, video-aided localization is prevalent, especially with the birth of cyber-physical systems to provide the ability to track the WCE in motion. Recently, researchers are interested with the extension of the capsule functionality, including effective wireless power supply and autonomous locomotion system making the next generation of endoscopy capsule development extremely challenging. One of the active WCE tracking procedures is based on image processing for estimating the capsule position on the foundation of the acquired images. Such techniques include Principal Component Analysis (PCA), Vector Quantization (VQ), and various machine learning techniques. For capsule localization problems, various techniques of have been addressed based on the Discrete Cosine Transform (DCT) or Fast Fourier Transform (FFT) for color change pattern analysis [31-36]. The data processing procedures can be elaborated in the Virtual Colonoscopy (VC) for achieving real endoscopic images from the capsule, for potential registration of the VC, and for capsule navigation and localization tracking.

VII. CONCEPT OF DIRECTION OF ARRIVAL (DOA)-/ TIME-OF-ARRIVAL (TOA)-BASED ENDOSCOPY CAPSULE LOCALIZATION

A. Direction of Arrival Estimation and Tracking

For array signal processing, the Direction-of-Arrival Estimation (DOAE) is a pervasive task that has a significant role in several applications including sonar, medical imaging, astronomy, radar, wireless communications, acoustics and military applications [23-25]. The DOAE of a signal is an effective approach for developing the received signal quality using smart antennas, which consist of a large number of antennas along with signal processing algorithms to improve the received signal and determine the DOAE from the signal quality point of view. The antenna can be arranged 2D as a linear/circular array, or 3D as cubic/spherical array. This antenna array is used for information transmission in a certain area or to estimate the DOA of a signal. Thus, the received signal quality enhancement is based on the performance of the employed method that used in the DOA of the signal. The DOAE algorithms are complex, where their performance relies on several parameters, namely the position, the used number of antennas, the antenna directivity, the spacing between the antennas within the array, the number of signal samples in the DOA estimation process. The basic concept of the DOA estimation is to focus/maximize the reception of the estimated/main direction and to reject all the received interferences from other directions. Numerous techniques have been established to estimate the signal DOA, such as the conventional techniques (Bartlett and Capon), subspace based techniques (e.g. ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques) and the MUSIC (MUltipleSIgnal Classification)), maximum likelihood techniques, integrated techniques and local polynomial approximation beam-former [26-30].

B. Sensor Array

Owing to the extreme use of low end of the spectrum, researchers are interested in finding higher frequency bands for more applications. However, with higher data rate and higher frequency, cross interference and multipath fading become the main issues. Thus, smart antenna systems with higher communication capacity are employed to solve these problems. Such systems proved to be very active in multipath signals and interference suppression. Using innovative signal processing along with an array antenna system instead of a single antenna can improve the DOA estimation resolution. In wireless systems, the receiving antennas can assemble signals, which are emitted by different sources. Assume D signals that attain from different D directions are received by an array of M elements with M weights.

Each received signal, *xm(k)*,can be represented by the k^{th} time sample to produce the array output *y* that is given by [31]:

$$\mathrm{y}(k) = \bar{\mathrm{w}}^{\mathrm{T}}.\bar{\mathrm{x}}(k) \quad , \tag{1}$$

where,

$$\begin{aligned} \bar{\mathrm{x}}(k) &= \left[\bar{a}(\vartheta_1)\bar{a}(\vartheta_2)....\bar{a}(\vartheta_D)\right].\begin{bmatrix} s_1(k) \\ s_2(k) \\ . \\ . \\ s_D(k) \end{bmatrix} + \bar{n}(k) \\ &= \bar{A}.\bar{s}(k) + \bar{n}(k) \end{aligned} \tag{2}$$

here, $\bar{w} = [w_1 \;\; w_2 \;\; .... \;\; w_m]^T$ denotes the array weights vector, $s(k)$ is the complex incident signals vector at time *k*, $\bar{a}(\vartheta_i)$ is the *M*-element array steering vector for ϑ_i DOA and at each array element, and $\bar{n}(k)$ is the noise vector. The *M* x *D* matrix of the steering vectors is given by $\bar{A} = \left[\bar{a}(\vartheta_i) \;\; \bar{a}(\vartheta_2)....\bar{a}(\vartheta_D)\right]$. The DOAE techniques aim to delineate a pseudo-spectrum function $P(\theta)$ that indicates of the angles of arrival based on the maxima versus the angle. Based on the carried out DOA estimation algorithm,

C. Direction-of-arrival and Time-of-arrival estimation

DOA and TOA based localization systems have a significant role in the WEC. One-way TOA measurement involves time synchronization between the transmitter and receiver [32]. In order to avoid the synchronization constraint, the two-way TOA measurement can be conducted. For WCE localization, such system may consist of a 2D cylindrical array, which feeds a signal transmitter and single/multiple receiver. For localization purposes, the setup does not necessitate wearing a special jacket, where the emitter transfers the signal to the WCE. Afterwards, the WCE responds and processes the signal back to an antenna array to compute the DOA, TOA and the total time of the signal transmission. The DOA and TOA computation procedure is similar to the passive radar technique. The transmission and WCE localization processes are based on the Wireless Local Positioning System (WLPS), which contains a transponder (TRX) and a Dynamic Base Station (DBS) [33]. The signal transmitter and antenna arrays are considered as a DBS and the WCE is considered as a TRX. Typically, the cylindrical antenna array is placed around the patient's body and processes complex algorithms for the DOAE through beam-forming techniques. Furthermore, an Inertial Measurement Unit (IMU) is used to equip the WCE for measuring the acceleration and orientation of the capsule. Thus, the WCE transmitted signal consists of image/IMU information. Nevertheless, over the time period, the IMU noise may lead to drift error in the localization process because of the random walk process of the patient during estimating the WCE motion using only the IMU measurement [34]. Consequently, the DOA and TOA additional measurement are employed to solve the localization drift error.

VIII. WCE LOCALIZATION TECHNIQUES

Object localization and tracking are critical issues in several medical applications. The most common localization approaches work based on different ways through i) magnetic tracking of a permanent magnet positioned inside the capsule by exterior magnetic sensors, ii) the capsule's emitted RF signals that can be determined by antennas located outside the abdomen, or iii) external magnetic field sources to localize the magnetic sensor inside the capsule. The localization of WCE can be determined by analyzing the transmitted and received signals. For inside the GI tract, among the localization approaches, TOA is considered one of the predominant techniques for acquiring accurate localization. Nevertheless, conducting experiments on the in-body TOA localization using inside real body, including inhibition and non-homogeneous environment inside the human body is complex. Thus, Finite-Difference Time-Domain (FDTD) [35-37] can be employed.

A. RSS Based Localization

A model of the association between the RSS and distance for known radio channel circumstances can be designed [38]. All localization procedures depend on a proposed model to acquire the results. The path-loss model has an imperative role for RSS based WCE localization. It is necessary to develop a precise in-body of surface path-loss model to increase the positioning accuracy. Typically, close receiver location to the transmitter leads to a strong signal being received and this may be applied to the RSS based WCE localization methods. Consequently, the path-loss model can be used to formulate the relationship between the RSS and the distance between transmitter and receiver as follows:

$$R_{SS} = T_p - P(d_0) - 10\beta \log\left(\frac{d}{d_0}\right) + S(d \geq d_0), \tag{3}$$

where, $P(d_0)$ is the path-loss at a specific distance from the transmitter, T_p is the transmitting power, β is the power gradient from the in-body tissue to the body surface and *S* signifies the shadow fading for the Gaussian distribution.

B. TOA Based Localization

TOA is measured based on the time of RF signals to travel between the transmitter and receiver, where the receiver location is typically unknown. The TOA-based localization methods are well-known due to their high accuracy compared to the RSS-based localization methods [39]. Its ranging distance can be gained by calculating the product of the measured time of arrival and signal propagation velocity:

$$R_{TOA} = t_{mesured} v_{\varepsilon_r}, \tag{4}$$

where ε_r signifies the RF signal velocity in a specific medium. Typically, the RF signal travels with different speeds via different organs, where the human body entails heterogeneous tissues with dissimilar electrical properties including conductivity and relative permittivity. Inside the human body, the speed variation becomes the major ranging error source in the ToA-based localization. Generally, high accurate synchronization requirement is essential which is indicated by a TOA error less than 1ns, where the localization resolution in- and around- the human body are frequently ranging from centimeters to decimeters. In order to solve such a drawback, the TDOA can be applied. For TDOA, in order to measure the received signals, two or more reference nodes are allocated. Afterwards, the time difference is derived by collecting the received signal arrival time. The main difficulty of employing the TDOA technique is the synchronization constraint and the required collaboration among all the allocated nodes.

C. POA Based Localization

Recently, the Phase of Arrival (POA) approach has become popular due to the widespread of Radiofrequency Identification (RFID). It has been further developed Body Area Network (BAN) applications in the form Phase Difference of Arrival (PDOA). Since numerous methods have been established to estimate the capsule location based on the transmitted RF signal from inside the human body to the sensor in the human body surface or to any additional sensor inside the human body. A novel spatial sparsity based localization technique has been proposed to directly estimate the capsule location without intermediate phase of first estimating the TOA or RSS [40]. Afterwards, a second phase of estimating the location has been conducted in order to achieve better localization accuracy in the BAN applications. Studying the channel model in- and out- of the body becomes essential.

Usually, the TOA-based ranging technique requires wider bandwidth, where using narrow band signal suffers from the ambiguity problem. In addition, the RSS-based ranging has low position localization accuracy. In order to overcome such drawbacks, using PDOA-based approaches for BAN applications becomes essential. Consequently, localization algorithms aim to extract a sequence of capsule location estimates from the measured RF signal of the sensors. The capsule's localization system is designed to assist physicians to define the relative location of the detected abnormalities. The received signal levels of the sensor array are organized together with the image data. Therefore, the localization algorithms are designed to provide consistent and robust observations, where the strongest signal can be received based on the sensor location. The sensors' locations relative to the umbilicus can be precisely defined and represented graphically. Typically, the localization processing results are a 2-D estimate of the location of the capsule at a specific time.

IX. RESEARCH DIRECTIONS AND CHALLENGES

Early endoscopic devices were lit by external inflexible light sources. Therefore, they were limited in terms of their usability. Subsequently, more modern endoscopes have become very compact one small diameter flexible tube devices, including a light source, CMOS chip or a charge-coupled device (CCD) for capturing images of the GI tract, and other equipment to take tissue samples. These endoscopes were unequipped with a digital imaging chip, but with an eyepiece lens and fiber optics. Imaging abilities, including illumination, modality and sensor characteristics are considered the most significant features in designing WCE systems [10]. The sensor/lens position determines the region imaged by the WCE. Most of the image sensors are attached to the capsule. Lenticular lens arrays or microlens arrays are established in laparoscopic surgery to deliver a multi-view image using a single sensor. Generally, the capsules should offer a widespread Field of View (FoV) to detect an adequate image of the tissue walls [41]. In the capsule design, the telemetry subsystem forms a bottleneck due to the size constraint limitations of the wireless communication system. Furthermore, video-based motion tracking is a critical issue, where at least one camera is used to equip the WCE to offer visual inspection of the GI tract and to track the capsule movement.

However, the inspection of the GT using the traditional endoscope is considered uncomfortable procedure for the patient along with the potential side effects, such as infection, organ perforation, and hemorrhage. Consequently, there is much research to cope with these difficulties. Exclusively, the small intestine is problematic due to its very long and convoluted path. Thus, the endoscope cannot be used to examine the entire length of the small intestine. This leads recently to develop a superior diagnosis tool for the small intestine, namely the wireless capsule endoscopy (WCE). This WCE is basically contains a lens, light source, radio transmitter, camera, and batteries. Afterward, the capsule travels via the digestive system, driven by peristalsis, and automatically captures a massive number of images during the eight hours traveling time. These images are wirelessly transmitted to a recorder/receiver worn outside the patient’s body [42].

Generally, the Body Area Network (BAN), also termed the Body Sensor Network (BSN) or Wireless Body Area Network (WBAN), is a wireless wearable network of computing devices or can be implants, embedded inside the body, mounted on the body surface in a fixed position or can be accompanied devices which humans can swallow or carry in different positions. Consequently, WCE is considered a type of WBAN that necessitates high data rates for high resolution video transmission to transmit the medical data. Thus, it requires the WBAN requirements, namely i) limited transmission range (0.01–2 m), ii) support of scalable data rate ranging from 1 kbps to several Mbps, iii) very low power consumption in sleep mode (0.1–0.5 mW) for longer battery life, iv) low latency, v) light weight devices and vi) Quality of Service (QoS) support for superior management of critical physiological signals [43].

The WCE captures images of the intestine through its attached camera and transmits the same to the computer’s receiver (or outside sensors) for further analysis and diagnosis. For example, the RF-based positioning and localizing approach has two-step estimation process to find the position, namely i) to guess the environmental coefficients, which are associated to the transmitter position including the ToF relative permittivity or RSS -based techniques path-loss coefficient, with a priori data on the environmental coefficient of medium or each organ, and ii) to uses the estimated parameters to successively guess the position based on a proper localization and tracking procedure.

Acquiring accurate capsule’s orientation and location during the capsule movement through the GI track is one of the most critical problems due to several reasons, namely i) the capsule position does give information about the tumors/bleeding location, or any other problematic matters in the GI tract; ii) it is nearly impossible to find solutions to other capsule endoscopy problems without position information, such as capsule tracking or the capsule working time for potential targeted drug delivery, and frame rate adaption for video transmission; iii) it is supportive to define the capsule insertion path to eliminate the invasive endoscopy repetitive attempts; iv) localization is vital to develop active actuation systems; v) orientation-and location-based path reconstruction allows several micro-robotic surgeries and exposes the undefined interior small intestine environment to researchers for educational objectives and vi) precise localization enables energy saving and transmission power control by turning the capsule device on and off. Presently, most the commercial software packages only offer 2D capsule route tracking [44]. Consequently, further research is required in localization algorithms and technologies of the WCE.

For positioning problem, there are several algorithms to determine the orientation and location of the attached sensor to the WCE. The RF signal-based location estimation approaches are promising due to their cost effectiveness and simple implementation. Consequently, these RF-based procedures have been exploited in the M2A biomedical capsules, MicroCam and SmartPill. Compared to DOA-, AoA- and RSS- based approaches; the ToF-based methods provide higher accuracy. Nevertheless, the human body intense absorption as well as the relative permittivity variations and uncertainties lead to errors in the ToF estimate. Moreover, the 402–405 MHz limited bandwidth in consistent with the Medical Implant Communication Services (MICS) inhibits the accurate ToF measurements [45].

In the M2A WEC, a transmitter inside the WEC sends data to the receivers' set that positioned on the patient's abdomen for commercial localization. Data location is calculated based on the strongest signal received by the capsule receiver from the closest receiver. However, due to low accuracy of 3.77 cm, this approach is not widely used [46]. Moreover, the time-based TDoA and ToF methods are unrealizable for near-field applications owing to the radio waves high speed of 3×108 m/s. Thus, highly accurate synchronized clocks of nanosecond level are essential to offer a 30 cm localization resolution [47]. Likewise, in the GI tract conditions, the AoA methods are inappropriate due to their low accuracy level in the indoor environments. Hence, none of the tracking and localization studies can offer an absolute solution to resolve the WBS positioning problem. However, due to the low implementation cost requirements and the several merits of the RF signal-based positioning approaches, they are preferred in numerous commercial wireless biomedical capsules (WBC), such as the M2A, MicroCam and SmartPill [45, 46].

Generally, unique problems occur for localization inside the human body due to its complex structure including the uncertain/variable signal propagation velocities, the peristalsis movement and the strong absorption of human tissue as well as the shadowing effects and path loss parameters in the entire human body. Additionally, due to multi-path effects triggered by the refraction at the human organs and tissues boundaries, detailed ToF and RSS models are complex; subsequently the signals received from the body-mounted sensors are distorted [47]. Consequently, alternative approaches based on hybrid techniques can deliver more accurate simultaneous orientation and location estimates, including fusion of video-based techniques and RF electromagnetic signal [48], fusion of magnetic-field-based and RF electromagnetic signal techniques [49] or fusion of other sensing modalities.

Several attempts have been made during the past few years to improve the localization technique's accuracy for the WCE [16, 40, 50]. Nevertheless, the existing localization techniques are not capable of offering precise WEC position information due to the non-homogeneous characteristics of body tissues and un-uniform body organ distribution. Researchers are thus inspired to use computational vision methods, such as Scale-Invariant Feature Transform (SIFT) and Speeded Up Robust Features (SURF) for tracking the video capsule motion to complement the prevailing wireless localization infrastructures. Moreover, other future work aspects can include the following: i) reconstruction of the GI tract using the emitted images from the WCE, ii) enhancing the visual motion tracking procedure in companion with GI tract animation, iii) combining numerous ranging and tracking approaches to achieve novel hybrid localization methods, and iv) develop advanced solutions for power management in the WCE.

In order to localize the RF source, such as the WCE inside the human body, Chandra *et al*. [51] proposed a phase difference based technique using a non-linear least square and arrival estimation. The phase difference of a signal arriving at multiple frequencies was employed to estimate the distance of the source to a receiver. In order to estimate the source initial position, linear least square estimation was utilized followed by a nonlinear least squares (NLS) technique to increase the localization accuracy. The position estimation error was in the order of 1 cm. Thus, this proposed method was efficient for the localization of an RF source inside the human body in the case of high Signal to Noise Ratio (SNR). Consequently, decreasing the noise in the WCE is essential to allow superior localization in the case of low SNR.

Bao *et al*. [52] developed a novel image processing approach for motion tracking of the EC. The work proposed a displacement analysis of the feature points between successive images to be captured while moving through the GI tract. For performance validation, virtual cylindrical tubes similar to the small intestine were used with virtual camera placed inside the tube to imitate the video capsule transition. The proposed technique established its ability to precisely estimate the tilt, linear transition, and rotation of the VC. Thus, as a future perspective, this proposed method can be improved to estimate the non-linear transitions as well to localize abnormalities. Aziz *et al*. [53] carried out a novel geolocation estimation method to obtain the position of a single unknown radio wave emitter. The proposed work derived a closed-form expression of the Cramer-Rao Lower bound (CRLB) for DOA. An advantage of this method is that it does not necessitate high computational complexity. Hence, it is recommended to apply the same procedure for DOA estimation of the WCE.

Based on the preceding studies, higher frequency bands tolerate higher transmission bandwidth between the antenna array receiver and the WCE. Nevertheless, this leads to higher penetration loss that causes low DOA estimation performance and poor SNR. The trade-off between the DOA estimation performance and the higher frequency bands' impact on the resolution of DOA becomes an emerging research aspect. In order to increase the directivity of the antenna beam pattern and to improve the resolution of DOAE, a large number of antenna arrays can be used. Furthermore, the DOA/TOA error statistics have a great impact on the localization performance of the WCE including the correlation between the TOA/DOA errors and the WCE's spherical positioning error, which is a challenging aspect for researchers. Furthermore, the influence of the irregular human body geometry on the signal transmission comprising the signal refraction can be considered for further investigations. Another research direction is employing distributed antenna array or other antenna configurations in the capsule design to allow free movement for the patients during the endoscopy examination process [1]. In addition, effective DOA localization and tracking techniques [53-68] can be employed to support the WEC system. Recently, developing algorithms to estimate the camera motion for accurate localization of the CE within the GI tract using visual features have become very challenging.

Generally, one of the critical factors that affect the WCE localization is the structure of the antenna array. Hu *et al*. [69] depicted that large number of antennas (sensors) and optimal localization algorithm lead to a higher accuracy of the orientation and position tracking procedure. Nafchi *et al.* [70] achieved high performance DOA/TOA-based endoscopy capsule localization and tracking by using two-dimensional (2D) circular arrays, where the emitter sent a signal to the WCE, which in turn replied the signal back to the antenna arrays (2D circular array). Afterward, the round trip TOA, and the DOA of the signals transmitted from the emitter to the WCE have been measured. Afterward, the same authors in [71] compared three antenna arrays sensor configurations positioning regarding different DOA measurement errors, and then considered different numbers of antenna arrays, namely 1, 2, 4, 8, 12, 16, 20 and 24. Five localization procedures have been employed for comparative study, namely i) TOA/DOA measurements only; ii) TOA/DOA with IMU measurement; iii) TDOA/DOA with IMU measurement; iv) IMU measurement only; and v) TDOA/DOA measurements only. The results established that the Extended Kalman Filter (EKF) achieved the position root mean square error (RMSE) of 2 cm or lower measurements with antenna array configuration of more than 12 antenna arrays. However, the accuracy enhancement becomes less significant (less than 2 mm) if the number of antenna arrays was higher than 16. Consequently, the optimal number of antenna arrays was 16. Moreover, in the antenna array system, higher computation complexity should be considered when large numbers of antenna arrays or TOA/DOA measurements are used for localization. This study depicted that the antenna array arrangement is minimally impacted the overall WCE localization accuracy performance. Furthermore, larger number of antenna arrays improved the position estimation performance of the WCE. This has opened up the way for researchers to study and develop new sensor arrays in order to increase the localization accuracy of the WEC.

X. CONCLUDING REMARKS

Traditional wired endoscopic devices are used for stomach and colon inspection. However, Capsule Endoscopy (CE) is a significant medical device for investigating the small bowel, where the Wireless CE (WCE) offers visual inspection of the whole gastrointestinal (GI) tract. The WCE has revolutionized the diagnostic process of small bowel diseases. Thus, it becomes the leading screening system for the entire GI tract. The WCE is considered as a promising system that overcomes the limitations of the traditional diagnosing equipment including comfortlessness due to cables and the incapability of investigating small intestine sections. In order to enhance the WCE, computational techniques can be implemented for accurate capsule localization and tracking. Accurate knowledge of the WCE position indicates the abnormality position has a fundamental role for different reasons, including accurate localization of lesions and automated CE navigation.

Typically, the WCE system includes developments to manage the capsule instantaneous localization process. The received signal transmission and attenuation are examined using an antenna array in the human body environment. Additionally, the connotation between the capsule location, capsule's transmitter position, signal reduction and the capsule direction are also assessed. Several localization techniques have been addressed, including magnetic-based localization, image-based localization, DOA-based localization, TOA-based localization and RSS-based localization.

The DOA estimation consists mainly of two independent supportive distributed sensor arrays representing the in-body sensory and body mounted devices. The localization error impact because of the sensor device's arbitrary movement as well as the body surface movement is considered in the localization problem formulation. In the WCE, it is significant to identify the electromagnetic wave direction that approaches the sensors that emitted by the in-body WEC. Thus, several DOA estimation algorithms can be developed with limited array size by considering the radio waves generated by the in-body sources. The WCE localization accuracy investigations concerning the WCE video motion tracking in the large intestine, tracking algorithms for a wide range of relative displacements and rotation angles, the TOA or the PDOA based ranging inside the human body are the main recent challenging areas. DOA estimation techniques of the Body Area Networks (BANs) can be used to support the WCE.

State-of-the-art research works clinically promise practicable intelligent algorithms to reduce the diagnostic errors, to localize the abnormalities and to assess the intestinal motility as well as to provide enhanced video quality and WCE localization. Recently, with the massive volume of the WCE data, big data and cloud technologies will become critical for efficient data management.

References

[1] M. Mylonaki, A. Fritscher-Ravens and P. Swain, "Wireless capsule endoscopy: a comparison with push enteroscopy in patients with gastroscopy and colonoscopy negative gastrointestinal bleeding," *Gut*, vol. 52, no. 8, pp. 1122–1126, 2003.

[2] G. Iddan, G. Meron and A. Glukhovsky, "Wireless capsule endoscopy," *Nature*, vol. 405, pp. 21–26, 2000.

[3] A. K. Hara, J. A. Leighton, V. K. Sharma, R. I. Heigh and D. E. Fleischer, "Imaging of small bowel disease: comparison of capsule endoscopy, standard endoscopy, barium examination, and CT," *Radiographics*, vol. 25, pp. 697–711, 2005.

[4] A. K. Hara, J. A. Leighton, V. K. Sharma, R. I. Heigh and D. E. Fleischer, "Small bowel: Preliminary comparison of capsule endoscopy with barium study and CT," *Radiology*, vol. 230, pp. 260–265, 2004.

[5] S. T. Goh, S. A. R. Zekavat and K. Pahlavan, "DOA-based endoscopy capsule localization and orientation estimation via unscented Kalman filter," *IEEE Sensors Journal*, vol. 14, no. 11, pp. 3819–3829, 2014.

[6] C. Hu, M. Q.-H. Meng and M. Mandal, "Efficient magnetic localization and orientation technique for capsule endoscopy," *Int. J. Infor. Acquisition*, vol. 2, pp. 23–36, 2005.

[7] M. Pourhomayoun, M. Fowler and Z. Jin, "A novel method for medical implant in-body localization," in *Proc. EMBC*, 2012, pp. 5757–5760.

[8] D. K. Iakovidis, D. E. Maroulis and S. A. Karkanis, "An intelligent system for automatic detection of gastrointestinal adenomas in video endoscopy," *Comp. Bio. Med.*, vol. 36, no.10, pp. 1084–1103, 2006.

[9] M. Sendoh, K. Ishiyama and K.-I. Arai, "Fabrication of magnetic acurator for use in a capsule endoscope," *IEEE Trans. Magn*. vol. 39, no. 5, pp. 3232–3234, 2003.

[10] G. Ciuti, R. Caliò, D. Camboni, L. Neri, F. Bianchi, A. Arezzo, A. Koulaouzidis, S. Schostek, D. Stoyanov, C. M. Oddo and B. Magnani, “Frontiers of robotic endoscopic capsules: a review,” *J. of Micro-Bio Robot.*, vol. 11, pp. 1–18, 2016.

[11] E. Spyrou and D. K. Iakovidis, “Video-based measurements for wireless capsule endoscope tracking,” *Meas. Sci. Technol.*, vol. 25, article 015002, 2015.

[12] M-G. Kim, Y-S. Hong, E-J. Lim, “Position and orientation detection of capsule endoscopes in spiral motion,” *Int. J. Precis. Eng. Manuf.*, vol. 11, pp. 31–37, 2010.

[13] M. Salerno, F. Mulana, R. Rizzo and A. Menciassi, “Magnetic and inertial sensor fusion for localization of endoluminal diagnostic devices,” *Comp. Assisted Radiology and Surgery*, vol. 7, 2012.

[14] Real-time pose and magnetic force detection for wireless magnetic capsule, by D. C. Natali, M. Beccani, P. Valdastri and K. L. Obstein. (2015, Dec 3). Patent US20150342501A1.

[15] M. Zhou, “On the Accuracy of Wireless Capsule Endoscope RF and Visual Localization,” (Doctoral dissertation, Worcester Polytechnic Institute), 2015.

[16] G. Bao, Y. Ye, S. Makarov, U. Khan, P. Swar, D. Cave, A. Karellas, P. Krishnamurthy and K. Sayrafian, “RF localization for wireless video capsule endoscopy,” *Int. J. Wireless Infor. Net.*, vol. 19, no. 4, pp. 326–340, 2012.

[17] Y. Ye, P. Swar, K. Pahlavan and K. Ghaboosi, “Accuracy of RSS-based RF localization in multi-capsule endoscopy,” *Int. J. Wireless Infor. Net.*, vol. 19, no. 3, pp. 229–238, 2012.

[18] M. Zhang, E. G. Lim, Z. Wang, T. Tillo, K. L. Man and J. C. Wang, “RF characteristics of wireless capsule endoscopy in human body,” in *Proc. GPC*, 2013, pp. 700–706.

[19] E. G. Lim, Z. Wang, J. H. Chen, T. Tillo and K.L. Man, “Investigation of EM wave propagation of the wireless capsule in human body,” in *Proc. EWDTS*, 2013, pp. 1–4.

[20] M. R. Yuce, G. Alici and T. D. Than, *Wireless Endoscopy - Encyclopedia of Electrical and Electronics Engineering*. Wiley, 2014.

[21] S. Yun, K. Kim and S. Nam, “Outer-wall loop antenna for ultra wide band capsule endoscope system,” *IEEE Antennas Wireless Propag. Lett.*, vol. 9, pp. 1135–1138, 2010.

[22] K. Kim, S. Yun, S. Lee, S. Nam, Y. J. Yoon and C. Cheon, “A design of a high-speed and high-efficiency capsule endoscopy system,” *IEEE Trans. Biomed. Eng.*, vol. 59, no. 4, pp. 1005–1011, 2012.

[23] H. Schweinzer and M. Syafrudin, “LOSNUS: An ultrasonic system enabling high accuracy and secure TDoA locating of numerous devices,” in *Proc. IPIN*, 2010, pp. 1–8.

[24] Y. Wu, G. Liao and H. C. So, “A fast algorithm for 2-D direction-of-arrival estimation.” *Signal Proc.*, vol. 83, no. 8, pp.1827–1831, 2003.

[25] M. E. Allam and J. F. Greenleaf, “Isomorphism between pulsed-wave Doppler ultrasound and direction-of-arrival estimation,” *IEEE Trans. Ultrason., Ferroelect., Freq. Control*, vol. 43, no. 5, pp. 911–922, 1996.

[26] T. B. Lavate, V. K. Kokate and A. M. Sapkal, “Performance analysis of MUSIC and ESPRIT DOA estimation algorithms for adaptive array smart antenna in mobile communication,” in *Proc. ICCNT*, 2010, pp. 308–311.

[27] S.U. Pillai, *Array Signal Processing*. Springer, 2012.

[28] V. Kumar and S. K. Dhull, “Techniques of direction of arrival estimation: a review,” *J. Elec. Electr. Eng.*, vol. 9, no. 1, p. 48–56, 2016.

[29] M. A. Ihedrane and B. R. I. Seddik, “Direction of arrival estimation using MUSIC, ESPRIT and maximum-likelihood algorithms for antenna arrays,” *Walailak J. Sci. Tech.,* vol. 13, no. 6, pp. 491–502, 2015.

[30] A. Sharma and S. Mathur, “Performance analysis of adaptive array signal processing algorithms,” *IETE Tech. Rev.*, vol. 33, no. 5, pp. 472–491, 2016.

[31] A. Vesa and A. Iozsa, “Direction-of-Arrival estimation for uniform sensor arrays,” in *Proc. ISETC*, 2010, pp. 249–252.

[32] J. Adams, W. Gregorwich, L. Capots and D. Liccardo, “Ultra-wideband for navigation and communications,” in *Proc. AC*, 2001, no. 2, pp. 785–792.

[33] Z. Wang and S. A. Zekavat, “Manet localization via multi-node TOA-DOA optimal fusion,” in *Proc. Milcom*, 2006, pp. 542–548.

[34] O. Salychev, “Inertial systems in navigation and geophysics,” Bauman Moscow State Technical University Press, Tech. Rep., 1998.

[35] J. Wang, O. Fujiwara, S. Kodera and S. Watanabe, “FDTD calculation of whole-body average SAR in adult and child models for frequencies from 30 MHz to 3 GHz,” *Phy. Med. Biol.*, vol. 51, no. 17, p. 4119, 2006.

[36] J. Thoné, S. Radiom, D. Turgis, R. Carta, G. Gielen and R. Puers, “Design of a 2Mbps FSK near-field transmitter for wireless capsule endoscopy,” *Sens. Act. A: Phy.*, vol. 156, no. 1, pp. 43–48, 2009.

[37] L. Xu, Q. H. M. Max and Y. Chan, “Effects of dielectric parameters of human body on radiation characteristics of ingestible wireless device at operating frequency of 430 MHz,” *IEEE Trans. Biomed. Eng.*, vol. 56, no. 8, pp. 2083–2094, 2009.

[38] X. Li, “RSS-based location estimation with unknown pathloss model,” *IEEE Trans. Wireless Comm.*, vol. 5, no. 12, pp. 3626–3633, 2006.

[39] A. Hatami and K. Pahlavan, “Performance comparison of RSS and TOA indoor geolocation based on UWB measurement of channel characteristics,” in *Proc. PIMRC*, 2006, pp. 1–6.

[40] M. Pourhomayoun, Z. Jin and M. L. Fowler, “Accurate localization of in-body medical implants based on spatial sparsity,” *IEEE Trans. Biomed. Eng.*, vol. 61, no. 2, pp. 590–597, 2014.

[41] A. Koulaouzidis and K. J. Dabos, “Looking forwards: not necessarily the best in capsule endoscopy?” *Ann. Gastroenterol*, vol. 26, no. 4, pp. 365–367, 2013.

[42] M. Mylonaki, A. Fritscher-Ravens, and P. Swain, ”Wireless capsule endoscopy: a comparison with push enteroscopy in patients with gastroscopy and colonoscopy negative gastrointestinal bleeding”, Gut, 52(8), Aug. 2003, pp. 1122–1126.

[43] K. M. S. Thotahewa, J. M. Redouté, M. R. Yuce, “Wireless Body Area Network and Ultra-Wideband Communication,” In Ultra Wideband Wireless Body Area Networks (pp. 1-18), 2014.

[44] A.Karargyris, A. Koulaouzidis, “OdoCapsule: Next-generation wireless capsule endoscopy with accurate lesion localization and video stabilization capabilities,” IEEE Trans. Biomed. Eng., vol. 62, pp.352–360, 2015.

[45] Y. Ye, “Bounds on RF Cooperative Localization for Video Capsule Endoscopy,” Ph.D. thesis, Worcester Polytechnic Institute, Worcester, MA, USA, 2013.

[46] T.D. Than, G. Alici, H. Zhou, W. Li, “A review of localization systems for robotic endoscopic capsules,” IEEE Trans. Biomed. Eng. Vol.59, pp.2387–2399, 2012.

[47] X. Guo, C.Wang R., Yan, “An electromagnetic localization method for medical micro-devices based on adaptive particle swarm optimization with neighborhood search,” Measurement, vol.44, pp. 852–858, 2011.

[48] G. Bao, K. Pahlavan, L.Mi, “Hybrid localization of microrobotic endoscopic capsule inside small intestine by data fusion of vision and RF sensors,” IEEE Sens. J., vol.15, pp. 2669–2678, 2015.

[49] I. Umay, B.Fidan, “Adaptive magnetic sensing based wireless capsule localization,” In Proceedings of the 10th International Symposium on Medical Information and Communication Technology (ISMICT), Worcester, MA, USA, 20–23 March 2016; pp. 1–5.

[50] K. Pahlavan, G. Bao, Y. Ye, S. Makarov, U. Khan, P. Swar, D. Cave, A. Karellas, P. Krishnamurthy and K. Sayrafian, “RF localization for wireless video capsule endoscopy,” *Int. J. Wireless Information Networks*, vol. 19, no. 4, pp. 326–340, 2012.

[51] R. Chandra, A. J. Johansson and F. Tufvesson, “Localization of an RF source inside the human body for wireless capsule endoscopy,” in *Proc. BAN*, 2013, pp. 48–54.

[52] G. Bao, L. Mi and K. Pahlavan, “Emulation on motion tracking of endoscopic capsule inside small intestine,” in *Proc. BIOCOMP*, 2013, pp. 1.

[53] M. R. K. Aziz, K. Anwar and T. Matsumoto, “A new DOA-based factor graph geolocation technique for detection of unknown radio wave emitter position using the first-order Taylor series approximation,” *EURASIP J. Wireless Comm. Net.*, vol. 189, 2016.

[54] J. Bulat, K. Duda, M. Duplaga, R. Fraczek, A. Skalski, M. Socha, P. Turcza and T.P. Zielinski, “Data processing tasks in wireless GI endoscopy: Image-based capsule localization & navigation and video compression,” in *Proc. EMBS*, 2007, pp. 2815–2818.

[55] P. Turcza and M. Duplaga, “Low-power image compression for wireless capsule endoscopy,” in *Proc.* IST'07, 2007, pp. 1–4.

[56] Y. Shen, P. Guturu and B. P. Buckles, “Wireless capsule endoscopy video segmentation using an unsupervised learning approach based on probabilistic latent semantic analysis with scale invariant features,” *IEEE Trans. Inf. Technol. Med.*, vol. 16, no. 1, pp. 98–105, 2012.

[57] L. Cui, C. Hu, Y. Zou and M. Q. H. Meng, “Bleeding detection in wireless capsule endoscopy images by support vector classifier,” in *Proc. ICIA*, 2010, pp. 1746–1751.

[58] S. Sainju, F. M. Bui and K. Wahid, “Bleeding detection in wireless capsule endoscopy based on color features from histogram probability,” in *Proc. CCECE*, 2013, pp. 1–4.

[59] X. Li, X. Chen, X. Xie, G. Li, L. Zhang and Z. Wang, “Pre-processing and vector quantization based approach for CFA data compression in wireless endoscopy capsule,” in *Proc. ISBI*, 2007, pp. 1172–1175.

[60] A. S. Ashour and H. M. Elkamchouchi, “Enhancement of moving targets tracking performance using the ICI rule,” *Alex. Eng. J*, vol. 46, pp. 673–682, 2007.

[61] A. S. Ashour, “LPA beamformer for tracking nonstationary accelerated near-field sources,” *Int. J. Adv. Comp. Sci. Applic.*, vol. 5, no. 3, pp. 148–154, 2014.

[62] A. S. Ashour and N. Dey, “Adaptive window bandwidth selection for direction of arrival estimation of uniform velocity moving targets based relative intersection confidence interval technique,” Ain Shams Eng. J., in press.

[63] N. Dey and A. S. Ashour, “Antenna design and direction of arrival estimation in meta-heuristic paradigm: a review,” *Int. J. Service Sci., Man., Eng. Tech.*, vol. 7, no. 3, pp.1–18, 2016.

[64] M. Pourhomayoun, M. Fowler and Z. Jin, “A novel method for medical implant in-body localization,” in *Proc. EMBC,* 2012, pp. 5757–5760.

[65] Y. Ye, U. Khan, N. Alsindi, R. Fu and K. Pahlavan, “On the accuracy of RF positioning in multi-Capsule endoscopy”, in *Proc. PIMRC,* 2011, pp. 2173–2177.

[66] K. Arshak and F. Adepoju, “Adaptive linearized methods for tracking a moving telemetry capsule,” in *Proc. ISIE,* 2007, pp. 2073–2708.

[67] M. Fischer, R. Schreiber, D. Levi and R. Eliakim, “Capsule endoscopy: the localization system,” *Gastrointestinal Endoscopy Clinics of North America*, vol. 14, pp. 25–31, 2004.

[68] J. Bulat, K. Duda, M. Duplaga, R. Fraczek, A. Skalski, M. Socha, P. Turcza and T. P. Zielinski, “Data processing tasks in wireless GI endoscopy: image-based capsule localization and navigation with video compression,” *in Proc. EMBS*, 2007, pp. 2815–2818.

[69] C. Hu, M. Q.-H. MENG, and M. Mandal, “Efficient magnetic localization and orientation technique for capsule endoscopy,” International Journal of Information Acquisition, vol. 2, pp. 23–36, 2005.

[70] A. R. Nafchi, S. T. Goh, S. A. R. Zekavat, “High performance DOA/TOA-based endoscopy capsule localization and tracking via 2D circular arrays and inertial measurement unit,” In Wireless for Space and Extreme Environments (WiSEE), 2013 IEEE International Conference on (pp. 1-6), 2013.

[71] A. R. Nafchi, S. T. Goh, S. A. R. Zekavat, “Circular arrays and inertial measurement unit for DOA/TOA/TDOA-based endoscopy capsule localization: Performance and complexity investigation,” IEEE Sensors Journal, vol.14, no.11, pp.3791-3799, 2014.

LIST OF FIGURES

Fig. 1. Capsule endoscopy [6]

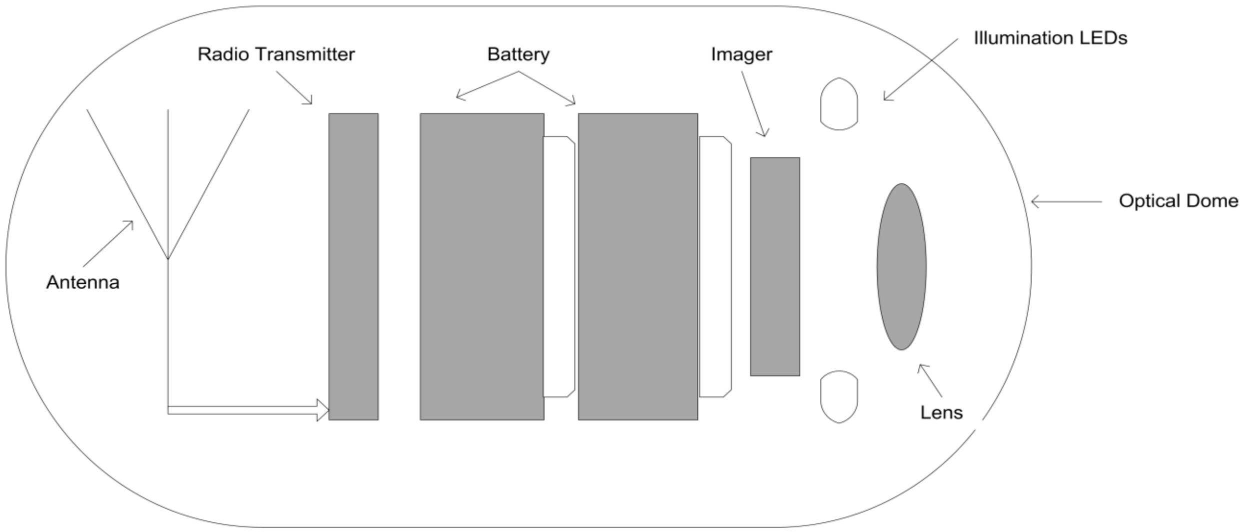

Fig. 1. Capsule endoscopy [6]