Novel Wireless Capsule Endoscopy Diagnosis System with Adaptive Image Capturing Rate

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Abstract: Wireless Capsule Endoscopy (WCE) is a device used to diagnose the gastrointestinal (GI) track, and it is one of the most used tools to inspect the small intestine. Inspection by WCE is non-invasive, and consequently it is more popular if compared to other methods that are traditionally adopted in the examination of GI track. From the point of view of the physicians, WCE is a favorable approach in increasing both the efficiency and the accuracy of the diagnosis. The most significant drawback of WCE is the time consumption for a physician to check all the frames taken in the GI track, in fact it is too long, and could be up to 4 hours. Many anomaly-based techniques were proposed to help physician shorten the diagnosis time, however, these techniques still suffer from high false alarm rate, which limits their actual use. Therefore, in this paper we propose a two stage diagnosis system that firstly uses a normal capsule to capture the whole GI track, and then we use an automatic detection technique that detects anomalies with high false alarm rate. The low specificity of the first capsule ensures that no anomalies will be missed in the first stage of the process. The second stage of the proposed diagnosis system uses a different capsule with adaptive image capturing rate to re-capture the GI tract. In this stage the capsule will use high image capturing rate for segments of GI tract where an anomaly was detected in the first stage, whereas, in the other segments of the GI tract a lower image capturing rate will be used in order to have better use of the second capsule's battery. Consequently, the second generated video, which will be inspected by the physician, will have higher resolution sequence around the areas with suspected lesion.

1 INTRODUCTION

The history of endoscope use to inspect internal organs can be traced back to the 19th century, in 1806, when German scientist Philipp Bozzini first invented the endoscope to inspect human bladder and bowel(Litynski, 1996). Since then, different types of endoscopy tools are constantly developed and improved, so for example the gastroscopy is used to detect gastric lesions, and colonoscopy for the intestinal lesions. In the past ten years endoscopy-related technology developed rapidly, and one of the most promising technology in this field is Wireless Capsule Endoscope (WCE). One of the benefits of WCE is that it serves inspecting the stomach and small intestine for illnesses. Unlike the usage of conventional endoscopic methods, in the application using WCE, there is no hose, which enables the patient to maintain normal life activities. Moreover, since the capsule endoscope is small enough to be swallowed, it significantly reduces the pain caused by traditional endoscope to the patient, even in comparison with endoscope with soft pipes. Furthermore, in comparison with endoscopy, colonoscopy and other traditional endoscope, where due to hose length and bending restrictions which limits the depth range of inspection of the human body, the WCE could be used to inspect the small intestine. Consequently, it becomes one of the most effective tools to check the whole section of the 5-7 meters small intestine(Triester et al., 2006), where it has been approved by the medical profession, due to its convenience, hygiene, and effectiveness.

The WCE is a capsule shaped device equipped with small-sized electronic circuitry, which includes the built-in LED that light the internal of the GI tract, the imaging system which captures images, a variety of sensors, battery, the transmitter module and the antenna and some other supporting components.The most popular WCE, developed and manufactured by Given Imaging (Given,). Other manufacturer, such as Olympus Pharmaceutical Company produces their own capsule. This latter produces the M2A-capsule endoscope (Olympus,), with a size of $11 \times 27mm$. After being swallowed, it continuously works for 7 to

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8 hours in the human body. During this period the WCE camera will take pictures of the digestive system at the rate of two frames per second, and eventually captures approximately $50,000$ color pictures. The capsule shell is made of special biological materials resistant to stomach acid and powerful digestive enzymes, and it moves , inside the GI tract, thanks to the gastrointestinal peristalsis.

In general, there are some limiting factors to the WCE, the first one is the low quality of the obtained images by the capsules. This limits the effectiveness of the image processing techniques, and consequently it may increase the probability of misdiagnosis. The main constraint for not being able to increase the resolution is the limited capacity of the battery. The second limiting factor comes from the fact that the movement of the capsule, inside the GI tract, dependents on the peristalsis, which means that the instant capsule speed varies due to the different internal structure of different individuals. Therefore, the current capsule system, with the existing image processing methods and image capturing rate cannot ensure high accuracy of diagnosis. In fact, when the capsule moves fast, misdiagnosis may exist.

In (Ping et al., 2011) a comparative study between the capsule endoscope and the double-balloon enteroscopy was carried out, the comparison is in terms of clinical and economic impact of both methods. In this study it was reported that the success rate of diagnosis is only 81.73% when the WCE was only used. However, it is stated that the accuracy will increase to 90.56% with the help of double balloon endoscopy.

To overcome some of the limitation of current WCE, intelligent image processing method could be used to improve the rate of successful diagnosis.Given Imaging Ltd, published a patent (Podilchuk, 2007), in which feature matching is applied on a number of captured images with the WCE and an existing database of images. This technique can be summarized as following, the captured images by the WCE are compared and matched with a database of images, using processing system that relay on lesions features in both sets of images. Then it highlight the images which are consistent with the required features. Thereby, the sensitivity of the system to the suspected lesions has been increased, and this helps doctors by shortening the detection time. However, this method still cannot overcome the weaknesses caused by the fast moving of the capsule in the areas with suspected lesions, and the limited number of captured pictures when the image capturing rate is fixed. Thus, although this method improves detection, it still has large possibility of misdetection.

To have more captured images is also an effective way to improve the detection rate of lesions. However, the storage and capturing capability of the capsule itself is limited. In fact, how to effectively adjust the image-capturing rate without a substantial increase in the energy consumption of the capsule, is one important factor that determines capsule efficiency. In the patent (Han et al., 2010), a technique to adjust the image capturing rate is proposed based on the observation that the speed of movement of the capsule, inside the GI tract, is different in different organs. So firstly, the time required for the capsule to reach different organs will be estimated. Then, via a built-in chip, the image capturing rate is adjusted once it reaches a certain preset time. This method compensates the fast movement of the capsule in some digestive organs, therefore, the possibility of successful diagnoses of illnesses is increased. However, tuning the image capturing rate of this method is not based on suspicious lesion areas. That is to say, the number of generated images for the lesions and the normal regions is the same in the same organ. So this will increase the burden of post-image processing and screening.

Thus, in general, the existing WCE is still unsatisfactory, due to many reasons, among them the image quality, and the image capturing rate which cause high probability false detection and misdetection. Therefore, this becomes the major obstacle for doctors to detect the patient's condition quickly and effectively. This paper proposes a new WCE system with adaptive image capturing rate, based on two capsules inspection paradigm. Thus the image capturing rate will be tuned during the second stage of inspection, based on the outcomes of the inspection with the first capsule. The first inspection serves to identify the suspected lesion regions.

2 NEW PROPOSED METHODOLOGY

The proposed WCE system and detection method aims to improve the amount of effective information and increase the temporal resolution of the captured video in the suspicious tracts of the digestive system. This objective is achieved by adjusting the image capturing rate of the capsule. Fig.1 shows the flowchart of the proposed diagnosis system, which aims through the use of the first capsule to detect any suspected lesion regions through the use of image recognition technique, and consequently to appropriately adjust the capture rate of the second capsule. The details of main elements of the system as shown in Fig.1 are as following: D11 is the first swallowed capsule, which is a traditional capsule with fixed image capturing rate and it includes a wireless transmitter module, and this capsule is used during the first diagnosis stage. D12 is the second swallowed capsule whose capture rate can be modulated, and it contains a wireless transmitter and receiver module. This capsule is used for the second stage of the diagnosis procedure, and this stage could start after completing the first diagnosis stage, or while it is still running. D1 and D2 are the patient carried built-in receiving apparatus with antenna arrays, D3 and D4 are the storage units for captured images, D5 and D6 are image feature identification devices, D7 is used for storing the captured imaged after image feature matching with image recognition system database, D8 is capsule capture rate controller and D9 is a transmitter.

Shown in the drawing process, the patient needs to swallow the capsule 1, D11, which can transmit signal to external body device. The transmission module inside can convert the captured images into wireless signals and then transmit them across the human body to the patient carried receiving apparatus D1. Images stored in the storage unit D3 will be determined whether has feature consistency with the feature images of various types of gastrointestinal lesions by D5. Then these matched images are marked and the two previous images of the matched image will also be marked. After swallowing the first capsule, D11 for a certain period of time, patient can swallow capsule 2, D12. Different from the Capsule1, the Capsule2 can be controlled by receiving external capture rate changing signal to adjust the capture rate in different intestinal regions. When D2 receives image signals captured by the Capsule2, these images will be identified by the image features device D6 and the results of comparison with marked images Capsule1. Once the image captured by capsules 2 is consistent with the feature image, the rate controller D8 sends the signal to speed up the capture rate of the capsule.

Fig.2 shows a schematic diagram of the existing design of the capsule; this kind of capsule will be used in the first stage of the diagnosis. In this figure, 1 point to the built-in optical system of a capsule, 2 stands for an image sensor, 3 is the image sensor controller, 4 is built-in capsule microprocessor, 5 is an illumination system, 6 is power supply device to provide energy to the various components of capsule, 7 is a wireless transmitting device, 8 is an antenna. The built-in microprocessor controls the wireless receiving module 7 and the image sensor controller 3. Meanwhile, the image sensor controller 3 controls the image sensor 2. The wireless transmitter module 7 transmits the signal to the patient carried receiving device, for further analysis and processing by the operation processing system.

Fig.3 shows a schematic diagram of the Capsule2, which is used in the second stage of the proposed diagnosis process. In this figure, 1 represents the built-in optical system of the capsule, 2 is the image sensor, 3 is the image sensor controller, 4 is built-in capsule microprocessor, 5 is an illumination system, 6 is power supply device to provide energy to the various components of capsule, 7 is a wireless transmitting device, 8 is an antenna. Different from the Capsule1, in the Capsule2 the wireless receiver and transmitter module 7 not only transmits the captured images to the carried receiver, but also serves to receive an external control signal to adjust the image capturing rate, thereby changing the capsule capture rate in the different tracts of the human digestive system. In Capsule2 the built-in microprocessor controls the wireless receiving module 7 and the image sensor controller 3, and the illumination system 5.

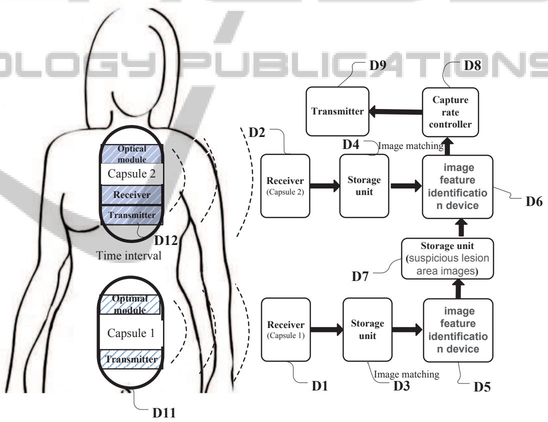


Figure 1: The block diagram of the overall system.

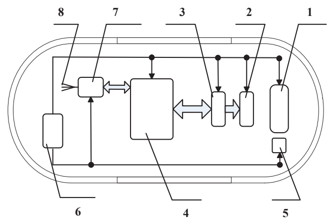


Figure 2: The main structure of Capsule1.

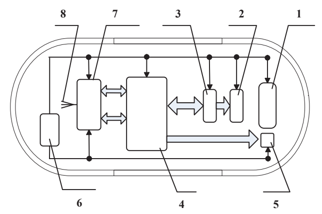
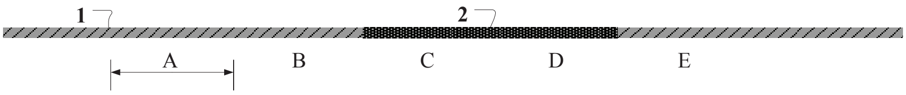


Figure 3: The main structure of Capsule2.



No.	A	B	C	D	E
Mark	Two before the image	One before the image	Lesion region image	Lesion region image	Normal

Figure 4: The adopted method for marking the suspected lesion area in few consecutive frames.

3 IMPLEMENTATION

As shown in Fig.1, the captured images obtained by the first capsule are transmitted through the human body to the external receiving apparatus D1, those images are stored in the storage unit, D3. Then every photo stored in D3 will be analyzed to detect various gastrointestinal lesions by the image processing system; this system will be tuned so as to have low specificity, in order to increase the chances of detecting lesions. Moreover, to reduce the probability of missing any lesions the system will mark few frames before and after the frame that contains the suspected lesions and these images will be stored into the storage unit D7. For example, let us suppose that among the frames f_a, f_b, and f_c, the frame f_c is suspected of having some lesions, in this case all the three images will be stored into storage unit D7. As for the Capsule2, D12, the patent will swallow it after a period of time of swallowing Capsule1. At beginning, Capsule2 will take pictures by low default speed (this speed could be set by doctors). Then the transmitted images by Capsule2 will be compared with those stored in D7. So, when some transmitted images are positively matched with the feature images in D7, the image capturing rate controller, D8, will transmit the signal to wireless capsule endoscope D12 to increase the capturing rate through transmitter D9. Therefore, the capsule can take pictures in suspected lesion area in a faster rate than before. Furthermore, when there is no more match between transmitted image by Capsule2 and feature image, the capture rate controller D8 will transmit new signal to change the capture rate back to the normal low speed in order to save battery's energy.

The process of lesion marking is shown in Fig.4. So, let us suppose that in series of captured images of digestive tract from frame A to E, there is one lesion area in image C and D (region 2: represented as the dark area). In this case, when the image feature identification device detects the lesion in picture C and D, in the video sequence generated by Capsule1, the picture A, B, C and D will all be marked. All marked images will be stored in a special database of image feature recognition apparatus, and when using the second capsule, i.e., Capsule2, all the new captured images will be compared with marked images database directly. At this point if some captured images by the second capsule match the marked images of the first capsule, then a signal is transmitted to increase the Capsule2 image capturing rate around the areas with suspected lesions. This will ensure that higher quality images will be generated around those areas, for latter analysis by the physician. When the built-in reception module in Capsule2 receives a rate control signal P25, as shown in Fig.7, the capsule will increase the imaging rate, otherwise it will keep the normal image capturing rate.

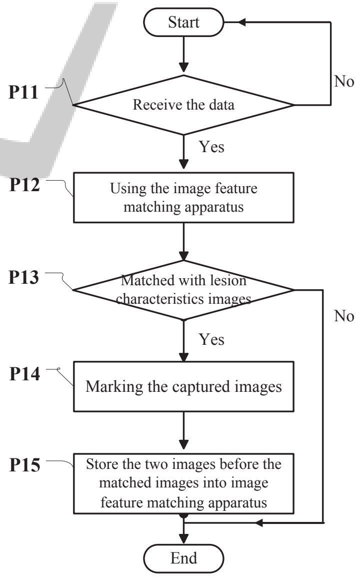


Figure 5: The flow chart of the working principle of the first capsule.

The flow chart reported in Fig.5 shows the working principle of the first capsule. When the data is received, the image feature matching apparatus will be used to match the captured image, by the capsule, with the lesion characteristics images P12. In this matching process, each captured image will be analyzed to see whether it matches the stored feature images in P13. If a match is found these images will be marked, P14, and stored into another database of image feature, P15. In Fig.6, the flow chart of the working principle of the second capsule is reported. This has similar working paradigm with the first capsule, except for the image capturing speed, which is tuned by D8 (in Fig.1). This latter unit will transmit a signal to the second capsule to increase the image capturing rate when a match is found with the stored feature images P13.

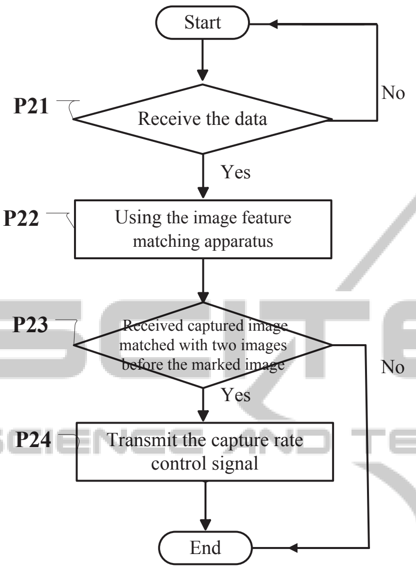


Figure 6: The flow chart of the working principle of the second capsule.

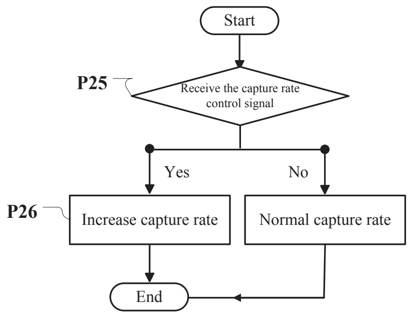


Figure 7: The control mechanism of the image capturing rate in Capsule2.

4 CONCLUSIONS

This paper proposes a new wireless capsule endoscope system, which comprises two diagnosis stages. The first one uses a normal capsule to capture the whole GI track. The generated video sequence will be analyzed to detect anomalies with high false alarm rate. The second stage of the proposed diagnosis system uses a different capsule with adaptive image capturing rate to re-capture the GI tract. In this stage the capsule will use high image capturing rate for segments of GI tract where an anomaly was detected in the first stage, whereas, in the other segments of the GI tract a lower image capturing rate will be used in order to have better use of the second capsule's battery. Consequently, the second generated video, which will be inspected by the physician, will have higher resolution sequence around the areas with suspected lesion. Therefore, this new type of wireless capsule endoscope system and method will be more efficient for clinical applications.

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