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White and narrow band image compressor based on a new color space for capsule endoscopy

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A B S T R A C T

In this paper, we present the design of a low power and hardware efficient image compressor integrated circuit for wireless capsule endoscopy application. The proposed compression algorithm supports dual-band imaging, that is, works on both white-band imaging (WBI) and narrow-band imaging (NBI). The scheme uses a novel color-space and simple predictive coding for optimized performance. Based on the nature of the narrow- and white-band endoscopic images and video sequences, several sub-sampling schemes are introduced. The proposed dual-band compressor is designed in such as way that it can easily be interfaced with any commercial low power image sensor that outputs RGB image pixels in a raster scan fashion, eliminating the need of large buffer memory and temporary storage. Both NBI and WBI reconstructed images have been verified by medical doctors for acceptability. Compared to other designs targeted to video capsule endoscopy, the proposed algorithm performs strongly with a compression ratio of 80.4% (for WBI) and 79.2% (for NBI), and a high reconstruction peak-signal-to-noise-ratio (over 43.7 dB for both bands). The results of the fabricated chip are also presented.

1. Introduction

Wireless capsule endoscopy (WCE) or video capsule endoscopy (VCE) is a state-of-the-art technology to receive images of human intestine for medical diagnostics [1,3]. In WCE, a patient ingests a specially designed electronic capsule which has imaging and wireless transmission capabilities inside it. While the capsule travels through the gastrointestinal (GI) tract, it captures images and sends them wirelessly to an outside data recorder unit. The data recorder stores the images and later the data is transferred to a personal computer (PC) where the images are reconstructed and displayed for diagnosis. The overall WCE system is shown in Fig. 1. The capsule runs on button batteries that need to supply power for about 8–10 h [2]. WCE is more comfortable for the patients than wired endoscopy. Moreover, examination of the small intestine can be performed using this technique.

When capturing endoscopic images, several changeable light modes are used, such as white-band imaging (WBI), narrow-band imaging (NBI), and auto-fluorescence imaging (AFI). The WBI, where white light is used to illuminate the GI surface, is the most commonly used imaging mode. In the NBI mode, two discrete bands of lights are used – one blue and one green, with center wavelength at 415 nm and at 540 nm namely [7]. Narrow band blue light displays superficial capillary networks, while green light displays subepithelial vessels and when combined, offer an extremely high contrast image of the tissue surface. Researchers found that NBI enhances the visibility of vessels and other structures on the mucosal surface over WBI and AFI imaging [8]. Generally, WBI is the default mode used in endoscopy; the system can be switched to NBI mode when required. In commercial products, NBI is implemented in wired-endoscopy (such as OLYMPUS PCF TYPE H180AL/I [44]) only,

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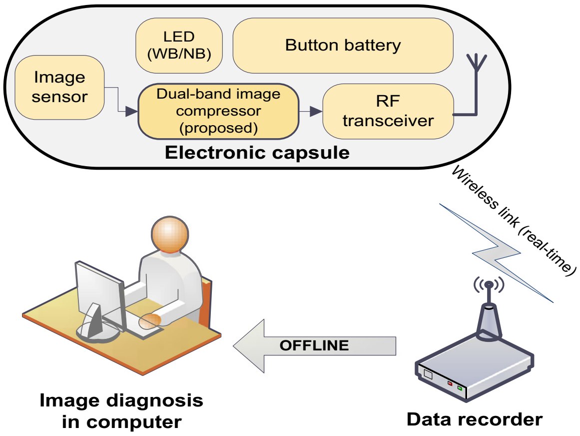

Fig. 1. Wireless capsule endoscopy system.

not yet in commercial wireless endoscopy. There is a few works on adding robotic capability of the capsule [4] and 3D imaging techniques [5]; however, they are at the proof-of-concept level.

Our focus in this paper is on the design of the image compressor of the capsule that supports both WBI and NBI modes (and hence referred as "dual-band" compressor). We introduce a novel and low-complexity color space for endoscopic images to achieve higher compression. The algorithm consists of lossless JPEG-based prediction [9] followed by golomb-rice coding [10]. Based on the nature of WBI, as well as NBI endoscopic images and video sequences, several subsampling schemes on chrominance components are applied. The proposed dual-band design can be directly interfaced with any digital-video-port (DVP) compatible commercial RGB image sensor [11,39,40] that output pixels in a raster scan fashion, eliminating the need of significant buffer memory, as well as temporary storage.

2. Background and motivation

There have been some works reported on the image compressor of the capsule. In [12–14], the Discrete Cosine Transform (DCT) based image compressors are proposed. In DCT based image compressors, 4×4 or 8×8 pixel blocks need to be accessed from the image sensor. However, commercial CMOS image sensors [11,39,40] send pixels in a row-by-row (i.e., raster-scan) fashion and do not provide buffer memory. So, to implement these DCT-based algorithms, buffer memory needs to be implemented inside the capsule to store an image frame [15]. In order to start processing of the first 8×8 block of a 256×256 size image, the compressor has to wait until the first 8×8 block is available, that is $256\times7+8=1800$ pixels (assuming progressive scan). Hence, a 5.3 kB buffer memory may seem enough (assuming 24 bits per pixel for a color image). However, without the full size buffer memory (i.e., 192 kB), the image sensor needs to be stopped (or paused) until the stored pixels are processed, as the image compressor would still be busy processing those pixels and there would be no additional memory available to store new pixels. The feature to pause in operation of sensors in the middle of a frame transmission is not commonly found in commercial image sensors. A possible solution to the problem is to use two buffer memory of size 5.3 kB, so that while the compressor works with pixels of one buffer, the new pixels continuously coming from the image sensor are stored in the other buffer. However, one needs to make sure that there is no timing violation between the compression time and input data-rate. Besides, the buffer memory takes large area and consumes sufficient amount of power which can be a noticeable overhead. For instance, a 256 kB customer owned tooling (COT) memory consumes 60 mW of power [16]. The work in [20] uses 103 kB integrated SRAM which consumes 70% of the total chip area and around 2 mW of power [19]. The estimated power consumption for a 256 kB SRAM would be approximately 5 mW, which is high enough for capsule endoscopy application. Other than transform coding, in [17], a compressor based on compressed sensing (CS) theory is described. The work is a subset of transform-based coding; as a result, the issues with transform coding still remain.

Among many image compression standards, the lossless JPEG and the JPEG-LS [9] can be good choices for compression for endoscopic capsule application, because of their simplicity, as well as capability to work with pixels coming in a raster-scan fashion. In [19,20], a JPEG-LS based image compressor is described. However, it needs memory to store at least one row of the image to support for various prediction modes. As a result, the design latency depends on the size of input image which is generally large. Besides, it needs approximately 1.9 kB register array to store key control parameters and contexts of JPEG-LS scheme [21]. Our group has recently presented a lossless compression algorithm [22] for capsule endoscopic application that produces good results compared with other lossless and lossy schemes. But, the algorithm is not fully optimized as it does not take the full advantage of the special features present in endoscopic images.

All the works that have been reported so far are based on white-band imaging (WBI). As the NBI is emerging as an effective tool in GI diagnosis, the authors in [23] presented an NBI image sensor chip. As the NBI is emerging as an effective tool in GI diagnosis, the authors in [23] presented an NBI image sensor chip. The work in [23] uses one single RGB image sensor to support both white band and narrow band imaging in capsule endoscopy. In the NBI mode of [23], three color components – G (green), B (blue) and N (clear) – are sent from the sensor to the data-recorder (using the RF link). The data are transferred to PC and the G, B, and N pixels are combined to form the color NBI image. It suggests that the NBI image (sent from image sensor) contains color information, and hence the proposed dual-band compression scheme, integrated with a new YEF color converter, is a useful technique as it works well for NBI, as well as WBI images. As of today, no prior work is found in the literature on the compression of NBI images.

Therefore, considering the existing literature and the application need, in this work, we have set the following design objectives for the compressor:

- The capsule must consume low power as the battery life is limited while it travels through the intestine.