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High-capacity multiple regions of interest watermarking for medical images

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ABSTRACT

Watermarking techniques have been widely used for copyright protection, broadcast monitoring, and data authentication in medical images to protect patient's private information against tampering by unauthorized persons. A region of interest (ROI) in a medical image contains valuable diagnostic information, and thus must be preserved to avoid medical misdiagnosis. Current state-of-the-art medical image watermarking techniques only allow single-ROI data preservation. Aiming for high embedding capacity and high image fidelity, we present a novel medical image watermarking scheme which allows multiple ROIs to be selected and kept lossless, whereas regions of non-interest (RONIs) are collated for watermark embedding. The watermark is compressed, and the embedding is conducted in frequency domain to avoid piracy. Experimental results show that the proposed technique has significantly achieved high-capacity and high-PSNR (peak signal-to-noise ratio) as compared against eight existing similar techniques. In addition, our technique allows flexible adjustment on a variable that controls the tradeoff between image fidelity and embedding capacity.

1. Introduction

Medical imaging devices have been widely used to produce numerous pictures of the human body in digital form. The field of telemedicine has grown rapidly in the recent decades with the rise of telecommunication and information technologies, which has eliminated distance barriers and provided immediate access to medical services all over the world. Telemedicine requires improved digital content protection as multimedia data while widely distributed across the Internet [8,14,16,21,32,35,37,39]. Copyright protection, broadcast monitoring, and data authentication are important issues of information security when medical images are exchanged between hospitals and medical organizations. Hence, image watermarking [3,6,9,10,12,13,25] is frequently applied as a process to embed data, such as signature images or textual information, into an image.

In general, two domains are used in image watermarking: spatial and frequency domains. In the spatial domain, many methods of watermarking have been proposed, such as the difference expansion approach which can embed some bits per pixel by utilizing correlation between pixels [29]. To increase embedding capacity and decrease distortion of the watermarked image for human perception, the difference expansion method was developed using generalized integer transform [1] and embedding in the least significant bits [2,33,34]. However, since data are inserted into the spatial domain of image

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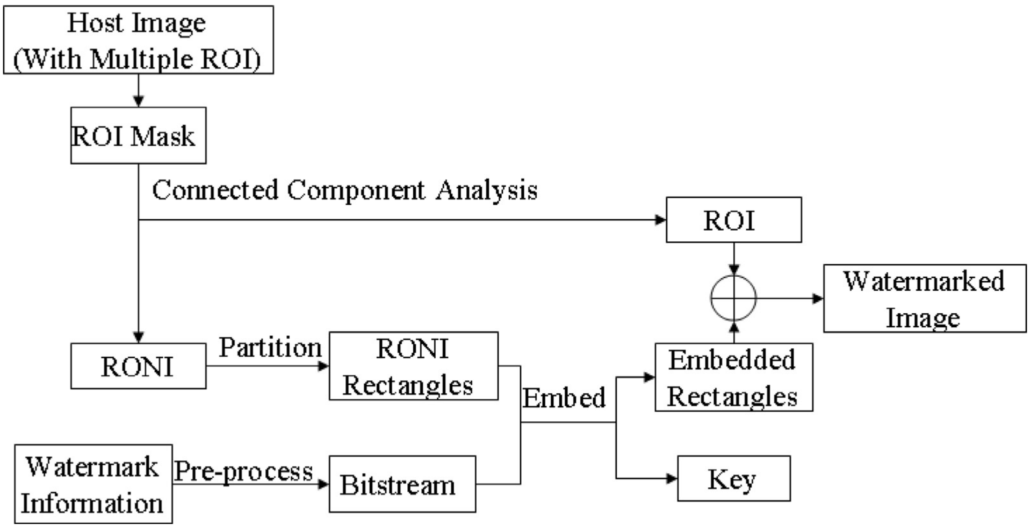

Fig. 1. The overall embedding process.

pixels, the embedded information is relatively easy to be detected by computer analysis. In the frequency-domain methods [4,15,17,18], a watermark is embedded into the coefficients of frequency domain of an image. The often-used transforms include DFT (discrete Fourier transform), DWT (discrete wavelet transform), and DCT (discrete cosine transform). Consequently, the embedded data are distributed around the entire image, which makes the watermark difficult to detect. However, the capacity of frequency-domain methods is often lower than that of spatial-domain methods.

Since the quality of medical images is critical for medical diagnosis, we need to preserve image quality while the embedding capacity is increased. Having this purpose in mind, we consider the idea of ROI (region of interest) based embedding methods [5,11,19,26,30,36]. A ROI contains critical information for diagnosis and must be saved without any distortion. The remaining RONI (region of non-interest) part can be utilized for watermark embedding, which allows lossy compression. Our previous work [26] was focused on single ROI watermarking and the correction of rounding errors, which are the deviations in converting real numbers to integers. In this paper, we focus on multiple-RONI medical image watermarking and propose a novel scheme to achieve high data capacity and high image quality in the frequency domain.

This paper is organized as follows. The proposed technique is presented in Section 2. Experimental results and analysis are described in Section 3. Conclusions are drawn in Section 4.

2. The proposed technique

The ROI is critical in providing medical diagnostic information for health care providers. To secure medical images through watermarking, the ROI must be preserved, so that watermark embedding is only applied on the remaining part of the image, which is called as region of non-interest (RONI). In order to enhance the embedding capacity without distorting the important diagnostic information, we take medical images with multiple ROIs preselected by experts as the input, and keep ROIs lossless. The remaining RONIs are used for watermark embedding and allow lossy compression. The ROIs are restricted to the rectangular shape due to the image transformation being applied. For an arbitrarily-shaped ROI, the smallest bounding box is used.

The RONI part constitutes a concave rectangle. First, the ROI and RONI are obtained through connected-component analysis [25]. Second, the concave RONI rectangle is decomposed into a minimum number of non-overlapping rectangles (i.e., partitioning), which are then transformed into the frequency domain. Third, we perform our embedding algorithm on the preprocessed watermark bitstream along with each RONI rectangle to generate an embedded rectangle and a corresponding key. Note that different types of watermarks can be embedded for robustness. Finally, the watermarked image is obtained by combining these embedded rectangles and the ROI part. Fig. 1 shows the overall embedding process.

During the decoding process, we obtain the ROI and RONI from the watermarked image, collate RONI rectangles, and perform our decoding algorithm on each RONI rectangle along with a key to extract the original rectangle and the bitstream. We obtain the original image by combining the generated rectangles and ROI, and retrieve the original watermark by reconstructing the bitstream. Fig. 2 shows the overall decoding process.

2.1. Watermark information preprocessing and reconstruction

The purpose of preprocessing watermark information is to generate a bitstream and enhance robustness. For medical images, we consider watermark images and textual data.