HEALTH DATA MANAGEMENT THROUGH MULTIPLE WATERMARKING OF MEDICAL IMAGES

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Abstract: Digital watermarking perspectives in medical applications have just recently started to be realized by the research community. Enhanced security of sensitive data, source and data authentication, efficient image archiving and retrieval, highlighting of diagnostically significant regions, form a set of health data management issues that can be jointly addressed by multiple watermarking. The paper proposes a wavelet-based multiple watermarking method, which focuses on medical applications. Conforming to the strict limitations applying to medical images, the method allows the definition of a Region of Interest, whose diagnostic value is explicitly protected, since the only additional information embedded therein aims at integrity control. The rest parts of the image are used for embedding of watermarks that convey the physician's digital signature, patient's sensitive data, and keywords for image retrieval. The robustness of the method is enhanced through a form of hybrid coding, which includes repetitive embedding of BCH encoded watermarks. The scheme has been tested on different medical image modalities with promising results.

Introduction

In recent years, the landscape of healthcare delivery and medical data management has significantly changed, as a result of the rapid advances in information and communication technologies. Complementary and/or alternative solutions are needed in order to confront the new challenges that have arisen in the health information management field, especially regarding protection of sensitive medical information. Digital watermarking is a very active research area with many applications; however, the perspectives of this technology in the medical field had not been realized by the research community until recently. Embedding of properly selected additional data directly into the medical image provides the possibility of effectively addressing critical health data management issues, including origin and data authentication, image archiving and retrieval, and sensitive data protection. A unified approach for the above requires multiple watermarks with different characteristics to be jointly embedded and independently retrievable. The literature on multiple watermarking, however, remains limited up to now.

Method

The proposed scheme applies multiple watermarking on medical images, aiming to simultaneously address a set of health data management issues. In accordance with the strict requirements concerning the acceptable operations on medical images, imposed by both ethical and legal limitations, the scheme preserves the quality of diagnostically significant image parts; specifically, it allows the definition of a Region of Interest (ROI), wherein the only additional information embedded aims at integrity control.

The algorithm inserts multiple watermarks in an image by applying Discrete Wavelet Transform and a proper quantization of coefficients. In general, wavelet-based watermarking schemes outperform in terms of robustness and transparency, by exploiting perceptual properties of the Human Visual System [1]. In order to enhance medical confidentiality protection and to provide efficient health data management and integrity control, the following different purpose-specific watermarks are embedded:

A signature watermark: it conveys the physician's digital signature or identification code for the purpose of origin authentication.

An index watermark: it carries keywords (e.g. ICD-10/ACR diagnostic codes, image acquisition characteristics, etc.) in order to facilitate image retrieval through indexing.

A caption watermark: it contains patient's personal and examination data, thus providing a permanent link between the patient and the medical data and an additional level of protection of sensitive information.

A reference watermark: it is embedded for the purpose of data integrity control [2], since the distorted reference watermark bits reflect possibly tampered parts of the image.

The watermarks are distributed in the wavelet subbands according to their robustness and capacity requirements [3]. As far as the signature watermark is concerned, robustness is of critical importance, due to the fact that even one error bit could result in authentication failure; on the contrary, the capacity required for the specific watermark is limited, since its length is restricted to the minimum needed to grant uniqueness of the conveyed identification code. On the other hand, index and caption watermarks also demand robustness but mainly increased capacity, especially the latter one due to the extended amount of data it contains.

As mentioned above, the embedding procedure is based on 4th level Discrete Wavelet Transform. The Haar wavelet is selected for the image decomposition in order to exploit the dyadic rationality of the resulting coefficients for increased watermark robustness. Specifically, if a multiple of 2^l, where l is the decomposition level, is added or subtracted from the Haar coefficients, the inverse wavelet transform produces an image with integer pixel values; in this way any rounding operation, which could distort the embedded watermark bits, is prevented [4].

The algorithm embeds the multiple watermarks in key-determined coefficients through a quantization scheme. According to the algorithm, any coefficient f selected to cast a watermark bit is assigned a binary value through the quantization function:

$$Q(f) = \begin{cases} 0, & if\ \lfloor (f-s)/\Delta \rfloor \ is\ even \\ 1, & if\ \lfloor (f-s)/\Delta \rfloor \ is\ odd \end{cases} \quad (1)$$

where s is a user defined offset for increased security, and Δ, the quantization parameter, is chosen to be equal to 2^l.

The multiple watermarks embedding procedure consists of the following steps:

Step 1: A 4th level Haar Wavelet Transform is applied to the image to produce a coarse image approximation at the highest decomposition level and a sequence of detail images (horizontal, vertical, and diagonal) at each of the four levels.

Step 2: The quantization function given in (1) is applied to each coefficient f that is to be watermarked. If the resulting value is equal to the value of the watermark bit to be embedded, the coefficient is left intact; otherwise the coefficient is modified as follows:

$$f = \begin{cases} f+\Delta, & if\ f \le 0 \\ f-\Delta, & if\ f > 0 \end{cases} \quad (2)$$

Step 3: A 4th level Inverse Wavelet Transform is performed to produce the watermarked image.

The extraction of the multiple watermarks is performed by 4th level Haar wavelet decomposition of the watermarked image and detection of the locations of the watermarks. The multiple watermark bits are extracted by applying the quantization function to each of the marked coefficients.

As previously mentioned, the watermarks are distributed in the subbands according to their requirements in terms of robustness and capacity. As the decomposition level increases, more watermark robustness and less available capacity are provided, due to the increasing energy concentration and the decreasing number of coefficients in ascending decomposition levels. In accordance with the requirements of the caption, index, and signature watermarks, the scheme embeds them into non-ROI coefficients of the second, third, and fourth decomposition level respectively. The reference watermark is embedded into coefficients of all levels covering the whole image, in order to provide an overall image tampering localization. In this way, the diagnostically important ROI is protected against any compromise on its quality, by containing only the information needed for integrity control.

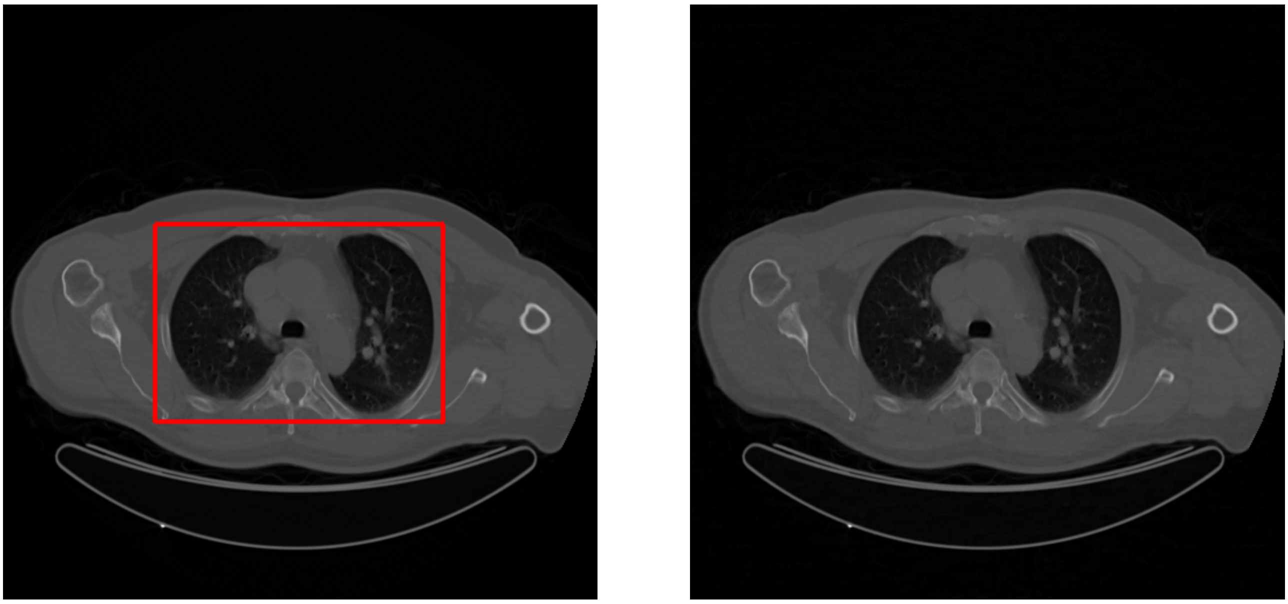
The selection of the coefficients to be watermarked is based on both a key and a ROI map. Initially, the key specifies the coefficients of all levels and subbands that will be watermarked; in the cases of signature, index, and caption watermarks however, the ROI map will finally determine which of the key-specified coefficients will be used by not belonging to the ROI. The wavelet domain ROI map is derived from the spatial domain ROI map, based on the spatial self-similarity between subbands [5]: the spatial ROI map is divided into blocks of 16×16 pixels; if any pixel of the block belongs to the ROI, the corresponding block of size 8×8 in the first decomposition level belongs to the ROI as well. This corresponds successively to a block of 4×4 wavelet coefficients in the second level, a block of 2×2 in the third level, and a single coefficient in the fourth decomposition level [6].

In general, horizontal and vertical subbands have resembling characteristics and are usually affected in a similar way by an image modification; therefore, they are selected to convey the data (signature, index, caption) and the reference watermarks respectively. In order to ensure imperceptibility, the coarse scale image approximation is excluded from the embedding process, given its energy concentration and consequently its crucial effect on image quality. The above mentioned actions allow the optimization of the proposed watermarking scheme in terms of robustness and transparency.

Results

The scheme was tested on three medical image modalities (CT, MRI, PET), with each set consisting of twenty 512x512 images; the images of each modality were collected by the same physician using the same equipment and system settings, in order to avoid deviation in image statistics. The signature and the reference watermarks were produced by a uniform random number generator, whereas the index and the caption ones were generated by ASCII coding of text files. The lengths of the signature, index, and caption watermarks were 128, 364 and 1,456 bits respectively.

Aiming to increase robustness of the watermarks carrying additional data (signature, index, caption), a form of *hybrid coding* [7] including repetitive



(a) (b)

Figure 1: Original and watermarked CT images. (a) Original image with a specified ROI (b) Resulting watermarked image

embedding of BCH encoded watermarks was applied. Specifically, the three watermarks were individually split into parts of equal length, which were incorporated into suitably selected BCH codes. Table 1 presents the selected BCH coding schemes and the number of BCH codes needed to comprehend each of the watermarks. After their BCH encoding operation, the watermarks were embedded three times each, thus providing the possibility to correct some errors through repetition decoding, before BCH decoding was applied to the extracted watermarks; repetition decoding involves forming the output watermark based on the most common bit values of the three extracted watermark copies.

Table 1: BCH Encoding Schemes for Each Watermark Type

Type of Watermark	Number of Bits	BCH Schemes	Iterat.	Total Number of Embedded Bits
Signature	128	(31,16,3)	8	248
Index	364	(255,91,25)	4	1,020
Caption	1,456	(255,91,25)	16	4,080

Due to the critical importance of medical image quality preservation, the performance of the scheme in terms of transparency was evaluated based on both perceptual and signal qualities. A physician examined the watermarked images and concluded that there was practically no visual difference between them and the original ones. Figures 1(a) and 1(b) show a test CT image with a selected ROI and the resulting watermarked image, respectively. Despite the fact that the Peak signal-to-noise-ratio (PSNR) is not well correlated with perceptual quality, it is an efficient measure of image distortion in terms of numerical values. PSNR is measured in decibels and is defined as in the following equation:

$$PSNR(I,\hat{I}) = 10\log_{10}\left[\frac{\left(\max\limits_{\forall(m,n)} I(m,n)\right)^2}{\frac{1}{N_I}\sum\limits_{\forall(m,n)}\hat{I}(m,n)-I(m,n))^2}\right] \quad (3)$$

where I and $\hat{I}$ are the original and watermarked images respectively, N_I is the number of pixels in the image, and $\max\limits_{\forall(m,n)} I(m,n)$ is the maximum gray-value of the original image. The denominator of PSNR is the average sample mean-squared error. Table 2 presents the average PSNR values of the watermarked images of each of the three modalities. The large PSNR values obtained, combined with the satisfactory perceptual quality of the watermarked images, illustrate the transparency of the scheme.

Table 2: Performance in Terms of PSNR

Image Modality	PSNR (dB)
CT	46.47 ± 0.06
MRI	46.37 ± 0.05
PET	46.66 ± 0.20

Tables 3 to 5 demonstrate the performance of the scheme in terms of robustness to JPEG compression, for each of the three tested medical image modalities (CT, MRI, and PET, respectively); as illustrated in these tables, the signature watermark, whose even one error bit would result in authentication failure, is extracted

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intact from all test sets even after JPEG75 compression. The index watermark resists JPEG compression with quality factors of at least 80, with this resistance standing even after JPEG75 compression in the case of the PET test set. As expected, the tolerance of the caption watermark to JPEG compression was less, due to the decreasing robustness in descending decomposition levels.

Table 3: Percentage of Error Bits in Watermarks Extracted from CT images after JPEG Compression (%)

Type of Watermark		Signature	Index	Caption
JPEG Quality Factor	JPEG95	0	0	2.0
	JPEG90	0	0	13.5
	JPEG85	0	0	20.4
	JPEG80	0	0	30.9
	JPEG75	0	5.5	37.8

Table 4: Percentage of Error Bits in Watermarks Extracted from MRI images after JPEG Compression (%)

Type of Watermark		Signature	Index	Caption
JPEG Quality Factor	JPEG95	0	0	0
	JPEG90	0	0	13.8
	JPEG85	0	0	23.4
	JPEG80	0	0	30.5
	JPEG75	0	4.4	39.3

Table 5: Percentage of Error Bits in Watermarks Extracted from PET images after JPEG Compression (%)

Type of Watermark		Signature	Index	Caption
JPEG Quality Factor	JPEG95	0	0	0
	JPEG90	0	0	12.6
	JPEG85	0	0	20.9
	JPEG80	0	0	30.8
	JPEG75	0	0	36.0

The above mentioned experimental results indicate the efficiency of the proposed scheme in terms of robustness and imperceptibility.

Discussion

A wavelet-based multiple watermarking scheme is proposed, which simultaneously embeds four types of watermarks into medical images, intending to provide origin and data authentication capability, enhancement of sensitive data protection, and efficient image retrieval. A combination of BCH encoding and repetition is performed during the embedding process, in order to improve robustness of the watermarks comprising signature, index, and caption data. The performed tests indicate the efficiency of the scheme in terms of robustness and imperceptibility. Future work involves additional tests regarding evaluation of the integrity control capability; besides, the wavelet-analytic nature of the algorithm is planned to be exploited in deriving image inherent characteristics, in order for the proposed scheme to accommodate content-based querying.

Conclusions

The performed tests illuminate the efficiency of the proposed multiple watermarking scheme in terms of robustness and transparency. Conforming to the strict limitations regarding manipulation of diagnostically significant image regions, the scheme has the potential to provide value-added services in a range of substantial health data management issues.

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