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Clinical Evaluation of Watermarked Medical Images

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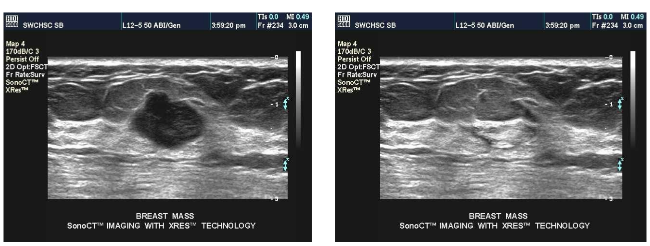
Abstract- **Digital watermarking medical images provides security to the images. The purpose of this study was to see whether digitally watermarked images changed clinical diagnoses when assessed by radiologists. We embedded 256 bits watermark to various medical images in the region of non-interest (RONI) and 480K bits in both region of interest (ROI) and RONI. Our results showed that watermarking medical images did not alter clinical diagnoses. In addition, there was no difference in image quality when visually assessed by the medical radiologists. We therefore concluded that digital watermarking medical images were safe in terms of preserving image quality for clinical purposes.**

I. INTRODUCTION

Nowadays it is becoming easier and easier to tamper with digital image in ways that are difficult to detect. For example, Fig. 1 shows two nearly identical images using readily available software (e.g. Adobe Photoshop). The cyst was removed from the image by using the healing brush tool. It is difficult if not impossible to tell which picture is the original and which has been tampered with. If this image were a critical piece of evidence in a legal case or police investigation, this form of tampering might pose a serious problem.

Image authentication techniques are usually based on two kinds of tools: digital signature and watermarking. A digital signature is non-repudiation, encrypted version of the message digest extracted from the data. It is usually stored as a separate file, which can be attached to the data to prove integrity and originality.



(a) (b)

Fig. 1 (a) original image (b) tampered image

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Watermarking techniques consider the image as a communication channel. The embedded watermark, usually imperceptible, may contain either a specific producer ID or some content-related codes that are used for authentication. Digital watermarking [1,2] offers a promising alternative to digital signatures in image authentication applications. The use of watermarks instead of digital signatures typically records additional functionality by exploiting inherent properties of image content.

The main advantage of digital watermarking is that the authentication information is directly embedded into the image data. As a result, the authentication information survives even when the host image undergoes format conversions. The digital watermark's capability for isolating manipulated image regions is another advantage. This functionality is known as the tamper localisation property. It is worth mentioning that both digital signatures and authentication watermarks are useful only for establishing the source of the image and detecting manipulations occurring after the signature/watermark has been inserted.

Most watermarking techniques modify, and hence distort, the host signal in order to insert authentication information. In many applications, loss of image fidelity is not prohibitive as long as the original and modified images are perceptually equivalent. On the other hand, in medical, military and legal imaging applications, where the need for authentication is often paramount, there are typically stringent constraints on data fidelity that prohibit any permanent signal distortion in the watermarking process. For instance, artifacts in a patient's diagnostic image may cause errors in diagnosis and treatment with possible life-threatening consequences.

Evaluation of the quality of watermarked medical image remains an important issue, by both objective and subjective means. Image quality has two implications: fidelity and intelligibility. The former describes how the reconstructed image differs from the original one, with peak-signal-to-noise ratio (PSNR) as a typical example, and the latter shows the ability through which the image can offer information to people, with classification-accuracy. Whether an objective measure on image quality is efficient or not, depends strongly on its accordance with subjective measure [3[. Most methods for watermarking data have been evaluated on the basis of minimizing an objective distortion measure such as PSNR at a given amount of watermark [4,5]. However, higher PSNR does not always mean better quality in the watermarked image because PSNR is not necessarily a subjective measure of the quality.

The next section would describe the process of watermarking in ROI and RONI as suggested by Coatrieux et al [6]. Subsequently, the process of clinical evaluation as well as the results would be discussed.

II. METHODOLOGY

A. Watermark RONI

We used method in [7] to embed the hash (256 bits) of the original image in the RONI of each image. Fig. 2 shows the definition used for ROI and RONI. Fig. 3 shows the general method used to embed watermark in the RONI.

Fig.2. ROI is defined inside the rectangle

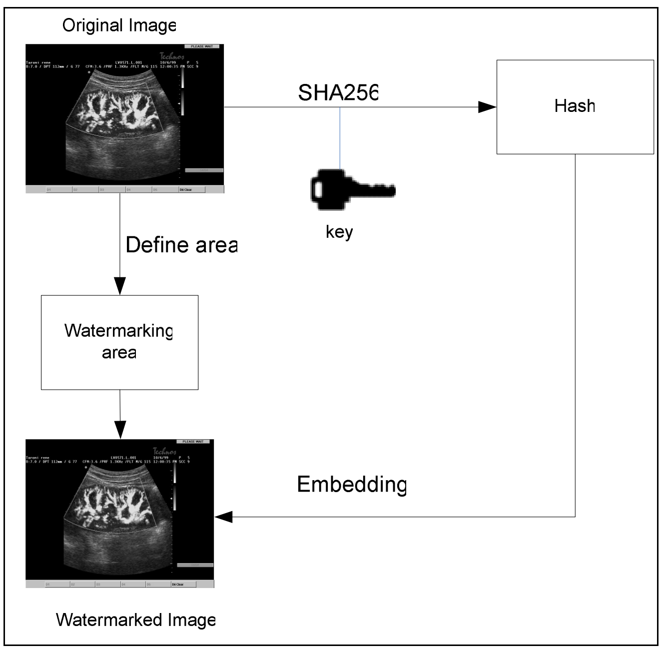


Fig.3. RONI Embedding method

B. Watermark ROI and RONI

Another watermarking technique was used to embed watermark in both ROI and RONI. This technique allows us to detect and localize tamper.

We propose a block of size 8 x 8 for better accuracy of localization, although the scheme will allow user to choose how accurate they want. We need to prepare a one to one block mapping sequence A → B→ C→ D → … → A for watermarking embedding, where each symbol denotes an individual block. The intensity feature of block A will be embedded in block B, and the intensity feature of block B will be embedded in block C, etc. Voyatzis and Pitas [8] presented a two dimensional, discrete Torus automorphism for creating a unique and random mapping of the pixels within an image. We use a 1D transformation based on [8] to get a one-to-one mapping:

$$\vec{B} = [(k \times B) \bmod N_b] + 1, \qquad (1)$$

where $B, \vec{B}, k \in [1, N_b]$, k is a secret key (prime number), and N_b is the total number of blocks in the image.

The generation algorithm of the block-mapping sequence is as follows:

- Divide the image into non-overlapping blocks of 8x8 pixels.
- Assign a unique integer $B \in \{1,2,3,..., N_b\}$ to each block from left to right and top to bottom, where N_b= (M/8) x (N/8).
- Randomly pick a prime number $k \in [1, N_b]$.
- For each block number B, apply equation (1) to obtain $\vec{B}$, the number of its mapping block.
- Record all pairs of B and $\vec{B}$ to form the block mapping sequence.

Note that the secret key, k, must be a prime in order to obtain a one to one mapping; otherwise, the period is less than N_b and a one to many mapping may occur. Table 1 lists some parts of the mapping sequence generated with Nb=40, k=23 (prime) and 26 (not prime) respectively. In this table, $\vec{B}$ starts to repeat at B=21 when k=26, which is not a prime.

TABLE 1
MAPPING OF BLOCKS WITH K=23,26 AND Nb=40

k	B	1	2	3	4	5	6	21	22	23	24
23	$\vec{B}$	24	7	30	13	36	19	4	27	10	33
26	$\vec{B}$	27	13	39	25	11	37	27	13	39	25

C. Embedding

For each block B of 8x8 pixels, we further divide it into four sub-blocks of 4x4 pixels. The watermark in each sub-block is a 3-tuple (v, p, r), where both v and p are 1-bit authentication watermark, and r is a 7-bit recovery watermark for the corresponding sub-block within block A mapped to B. The following algorithm describes how the 3-tuple watermark of each sub-block is generated and embedded:

- Set the LSB of each pixel within the block to zero and compute the average intensity of the block and each of its four sub-blocks, denoted by avg_B and avg_Bs, respectively.
- Generate the authentication watermark, v, of each sub-block as:

$$v = \begin{cases} 1 & \text{if } avg\_Bs \geq avg\_B, \\ 0 & otherwise, \end{cases} \qquad (2)$$

- Generate the parity check bit, p, of each sub-block as:

$$p = \begin{cases} 1 & \text{if } num \text{ is } odd, \\ 0 & otherwise, \end{cases} \qquad (3)$$

where num is the total number of 1s in the seven MSBs of avg_Bs.

- From the mapping sequence generated in the preparation step, obtain block A whose recovery information will be stored in block B.
- Compute the average intensity of each corresponding sub-block As within A, and denote it avg_As.
- Obtain the recovery intensity, r, of As by taking 7 MSB in avg_As. Seven bits is used as we are using one bit for watermarking .
- Embed the 3-tuple watermark (v, p, r), 9 bits in all, onto the LSB of of each pixel in a 3x3 block within Bs as shown in Fig. 4, where r1 is the MSB, e.g. if the intensity of As is 155, r1, r2, r3, r4, r5, r6 and r7 is 1, 0, 0, 1, 1, 0 and 1 respectively.

v	P	r1
r2	r2	r4
r5	r6	r7

Fig.4. Watermark positioned in the LSB of 3x3 block

For ultrasound images of 800X600X8, the total watermark bits are 480K, with average PSNR of 54.15dB. Fig. 5 shows watermark distribution in the whole image with PSNR 54.15 dB. Fig. 6 shows an example of an original image, the same image with watermark embedded in RONI and watermark embedded in the whole image (both ROI and RONI).

D. Clinical Evaluation

This section will describe our clinical evaluation. Seventy-five images (21 x-rays, 27 CT films and 27 ultrasound images) from our hospital teaching bank were watermarked twice, in region of non-interest (RONI) and in and both ROI and RONI making 225 images altogether.

Three assessors whom were all consultant radiologists were randomly given a selection of both watermarked (WM) and non-watermarked (nWM) images. Each received 75 images, 25 nWM images or the original and 50 WM images. They were asked to give a clinical diagnosis aided with a short clinical stem.

The assessors' responses were then compared with the original diagnoses and an independent radiologist assessed vague responses. We also asked the assessors to comment on the quality of the images if it was deemed hindering diagnostic evaluation. If a clinical diagnosis was not possible, the assessors had to state reasons. We used Chi Square test statistics to test the difference between the three groups and $P<0.05$ was considered significant.

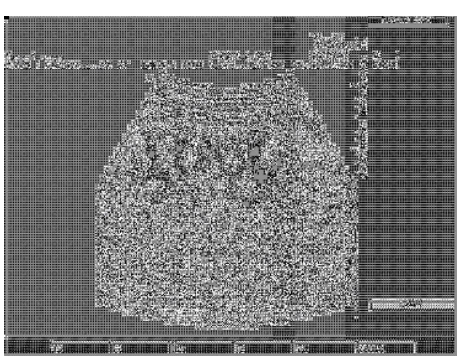
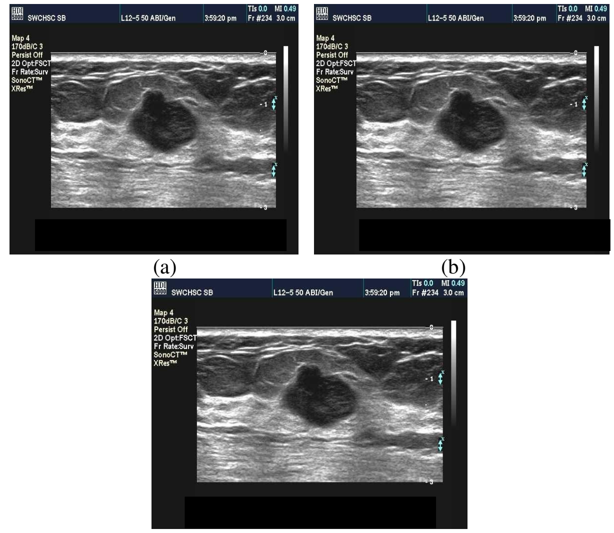


Fig.5. Watermark distribution for the whole image with PSNR=54.15 dB



(a) (b) (c)

Fig.6. (a) original image (b) RONI watermarked image (c) RONI and ROI watermarked image.

II. RESULTS

The three assessors evaluated 225 images. Each received 25 nWM and 50 WM (ROI and RONI) images. Tables 2 and 4 listed the image types and diagnoses used in the study respectively. Table 3 gave the number of correct responses (CR) from each assessor. Chi Square test showed no significant difference between the three groups.

There were five wrong responses from assessor 1, 3 from assessor 2 and 4 from the last assessor. These were all incorrect responses when assessed by the independent radiologist. In addition, image quality was not implicated in all wrong responses. Overall, there was also no comment on image quality from all the assessors. Chi Square test on CR from the three groups (nWM, RONI and ROI) was not statistically significant ($P=0.5$).

TABLE 2
TYPES OF IMAGES USED IN THE STUDY

	X-rays (n=21)	CT Films (n=27)	Ultrasound (n=27)
Head	0	6	0
Chest	19	16	0
Abdomen	0	4	14
Pelvic	0	1	8
Deep Veins	0	0	4
Ankle	1	0	0
Calf	0	0	0
Thigh	0	0	1
Shoulder	1	0	0

III. CONCLUSION

From this study, we concluded that watermarking medical images did not alter clinical diagnoses. It was also evident that the area where watermarking was embedded was immaterial as both sites; ROI and RONI gave similar results when they were clinically assessed. We noted the previous suggestion by Coatrieux et al [6] to preserve ROI to safeguard diagnostic zone but our study has shown that ROI could also be an area for watermarking.

TABLE 3
IMAGE TYPES (n=225) GIVEN TO EACH ASSESSOR (A) AND THE CORRECT RESPONSES (CR)

	A 1	A 2	A 3	Total (CR)
ROI+RONI(CR)	23 (22)	27(25)	25 (23)	75(70)
RONI(CR)	27 (26)	23 (23)	25 (24)	75(73)
nWM (CR)	25 (23)	25 (25)	25 (24)	75(72)
Total images (Total CR)	75 (70)	75 (72)	75 (71)	225

TABLE 4
ALL THE DIAGNOSES OF IMAGES USED IN THE STUDY

	X-rays (n=21)	CT Films (n=27)	Ultrasound (n=27)
Intra-cerebral Bleed	0	2	0
Cerebral Tumour	0	1	0
Hydrocephalus	0	1	0
Subdural Bleed	0	1	0
Extradural Bleed	0	1	0
Pneumonia	3	1	0
Lung Malignancy	4	4	0
Mediastinal Mass	2	2	0
Pneumothorax	2	1	0
Pleural Effusion	3	3	0
Pleural Mass	2	1	0
Bronchiectasis	1	2	0
Pulmonary Fibrosis	2	1	0
Thoracic Empyema	0	1	0
Cholecystitis	0	0	2
Liver cysts	0	0	1
Liver Metastases	0	1	2
Hydronephrosis	0	0	2
Abdominal Aortic Aneurysm	0	1	1
Renal Mass	0	2	3
Cervical Mass	0	1	2
Uterine Mass	0	0	2
Ovarian Mass	0	0	2
Endometriosis	0	0	2
Ascites	0	0	1
Cirrhosis	0	0	2
Fractured Humerus	1	0	0
Fractured Tibia	1	0	0
Thigh Abcess	0	0	1
Deep Veins Thrombosis	0	0	4

In addition, there was no difference in image quality when visually assessed by medical radiologists. We are therefore confident that digital watermarking is safe in terms of preserving image quality. Both physicians and radiologist should be reassured that this technique of digital watermarking ensures image quality preservation and therefore clinical diagnoses can be made with high reliability.

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