Biomedical Signal Processing and Control 29 (2016) 44–52

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

# A new approach to fully-reversible watermarking in medical imaging with breakthrough visibility parameters

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ARTICLE INFO

*Article history:*
Received 11 February 2016
Received in revised form 19 April 2016
Accepted 19 May 2016

*Keywords:*
Communication
DICOM
Medical images
Security
Watermarking
Visual cryptography
RONI

ABSTRACT

Securing of medical images against intentional or accidental modification is a general issue in modern radiology. Watermarking, with its data-centric security, is very convenient for this purpose. We proposed a new method of fully reversible watermarking in medical imaging by combining the advantages of three traditional approaches—Reversible, Zero and RONI watermarking. The new method achieves exceptionally high values of Peak Signal to Noise Ratio and Structural Similarity index. The article evaluates the pros and cons of current methods of watermarking in medical imaging. Keeping the pros and eliminating the cons of the methods allows a new approach. Specific methods are selected and their application in practice described in detail. Application of the proposed method on a database of 6000 medical images from common hospital operations delivers very promising results which are discussed at the end of the article.



## 1. Introduction

Digital watermarking, a technique of inserting additional information into digital data, is widely used in today's digital world to secure data (It is difficult to find and remove this information from watermarked files). As medical image data processing is almost fully digitalized in healthcare institutions these days, to ensure the security of digital data is of very high importance.

Watermarking brings the undeniable advantage of security embedded directly into the data itself (i.e. Image Centric Security), which ensures the inseparability of data and the security measures. Medical image processing can be very sensitive, even on very slight changes in the image visual appearance. Modification of even a single pixel in the medical image may in some cases affect the overall information contained in the image, and so might influence the diagnosis and consequently might threaten the health or even the life of the patient. Therefore, it is necessary to approach watermarking in the area of medical imaging quite differently compared to the other areas of interest.

Section 2 of this article describes the good and bad features of the most common watermarking methods used to secure medical image data. Section 3 then proposes a new method of connecting the advantages and eliminating the disadvantages of Zero and Reversible watermarking. Section 4 describes the detail and practicalities of the Zero watermarking method used for the insertion and removal of watermarks in Regions of Interest (ROI). Section 5 contains details and a practical description of the Reversible watermarking method used in Regions of Non-Interest (RONI). Section 6 explains the principle of connection and data exchange between both sub-methods. In last section, there are experimental results of the new method and comparisons with other methods.

## 2. Principal problems of watermarking in the field of medical imaging

Watermarking has many advantages. Among the most important is the direct insertion of security measures into the data, called *Data Centric Security*. Security is directly present in the secured data and without knowing the right algorithms, is unrecoverable. Another advantage is that it is not directly obvious that data are secured. Nevertheless, watermarking is not deployed in common practice, because each method has its limitations, as described above. From the description below and comparison of the most common methods of watermarking of medical images [1] arise problems which make their use difficult or completely exclude them from everyday operation in medical practice [2].

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http://dx.doi.org/10.1016/j.bspc.2016.05.005

### 2.1. Watermarking in RONI

The change of a single bit in a medical image could be a problem for correct diagnosis. Using RONI-only watermarking, watermarks are stored only in parts that do not contain information important to diagnosticians. Selection of the RONI (Region of Non-Interest) can be either automatic or manual. The reliability of automatic detection of important areas depends on the chosen method. In practice, different methods of automatic RONI selection are mostly used [3–5]. There is considerable similarity to previously-known watermarking methods applied to the RONI area, but on the other hand, there is a lack of protection in the part of the medical image that is most important. The need to search RONI makes watermarking more difficult and can cause errors with both automatic and manual ROI labeling processes.

### 2.2. Reversible watermarking

Reversible watermarking is based on the process of watermark insertion into a medical image, transmission of the watermarked image, and the complete removal of the watermark from the image on the recipient's side. After watermark removal, the original image is completely restored and unchanged. Once the watermark is removed from the image, the image is no longer protected. Evidently, there is a requirement to transmit those differential values in a secure way. These differences are used at the recipient's side to remove the watermark and reconstruct the original image [6–10]. As an advantage of this method, we can mention the possibility of securing the whole image by robust watermarking methods and higher capacity than RONI watermarking. The major disadvantage is the need to create another channel for secure transport of differential information.

### 2.3. Zero watermarking

In zero watermarking, a watermark is not inserted directly into the watermarked data, but is kept separate for later comparison. As a result, it can be considered as a lossless since no data are modified. It is primarily used to ensure copyrights protection. It is based on a Certification Authority (CA) [5,10].

The main advantages are high robustness and zero distortion of the watermarked image. The big disadvantage is the need to build a fairly complex CA system for watermark storage and comparison.

### 2.4. Watermarking with image change not affecting diagnosis

Methods which change the values of some bits in the resulting image can also be used for watermarking of medical images. However, the change has to be so insignificant that it cannot in any way affect the final diagnosis that the study was intended for. In general, this method can be used with images obtained using scanning modalities with a higher resolution than is needed for accurate diagnosis. This type of watermarking is typically suitable for X-ray images such as fractures, where important information is seen from surrounding pixels, regardless of the exact shade of grayscale in the given bit depth. This method is unsuitable for images intended for the diagnosis of metastasis for which accurate bit pixel value as well as its surroundings is critical [11].

## 3. Proposed concept: a combination of Zero and Reversible watermarking

By suitably combining particular methods in the right way, the disadvantages of each method will be eliminated and their strengths emphasized. This could remove the last obstacle to the use of watermarking in practice to secure medical images.

The proposed method consists of the combination of Zero, Reversible and RONI watermarking. The basic idea is that the image is divided into two parts: ROI and RONI. RONI is the part of the image where small changes do not distort medical information. ROI is the rest of the image.

Detection of RONI on a representative sample of medical images (from a database of more than 60 000 images) was carried out in study [20]. Finding the RONI is done automatically. The detection method is based on comparing pairs of neighboring vectors. Vectors contain pixel values of rows and columns. The comparison is made in each direction – from top, bottom, right and left – from the edges to the center of the image. Along each vector, the border between ROI and RONI is the place on the vector which differs from the previous point by more than the specified threshold. In the study, the threshold was defined as 10% similarity, after practical tests. Detailed information can be found in Ref. [20]. More accurate determination of RONI taking into account object contours, as in Ref. [21], is not a subject of this research. This study proved that all examined medical images, which we consider to be a representative sample of medical imaging, have a RONI of size 11% or more of the whole image. This is sufficient for the proposed method, in which it is calculated with 10% of RONI.

The size of ROI is expected to be significantly greater than RONI (80–90%). The ROI is secured by Zero watermarking. The information needed to remove the watermark from the secured ROI is called the *Secret Share*, which is embedded as a watermark into RONI using Reversible watermarking, which must have high capacity due to its size. This secures the image without changing its most important parts, and allows complete reconstruction of the original image as well as verification of its authenticity.

Watermark extraction and reconstruction of the original image includes: extraction of the Secret Share by Reversible watermarking as a watermark from RONI; calculating the *Public Share* with Zero watermarking in ROI; and joining them into the original watermark. Then, the original image data in the RONI region is reconstructed with Reversible watermarking and connected with the unchanged ROI in its original form.

The main advantage of this method is securing not only RONI, but also the most valuable part of the image—ROI. This major part of the picture is protected in its original form with Zero watermarking. Furthermore, this solves the problem of creating a special secure information channel, which is necessary in Reversible watermarking. This channel is made by hiding information necessary to extract the watermark with Zero watermarking in RONI. The main watermarking methods' property space, and the locations of ROI and RONI watermarking, are shown in Fig. 1.

While for watermarking in ROI, imperceptibility and robustness are essential, for watermarking in RONI, capacity and possibly robustness are particularly important.

## 4. Implementation of Zero watermarking in ROI in the context of the proposed concept

The watermarking method for ROI is based on the Zero watermarking principle. It came out of the method described in Ref. [12], which combines the robustness of watermarking using dual-tree complex wavelet domain and the benefits of visual cryptography.

It consists of three parts: the concealment process, the extraction process and watermark reduction. The process of watermark hiding uses Dual Tree Complex Wavelet Transform (DT-CWT) [13] to create a binary matrix B based on the low-low (LL) sub-band coefficients. From the matrix B and the watermark, the Secret Share is then generated using visual cryptography.

The same procedure is used for removing the watermark to generate a Public Share. After overlapping (logical OR) the Secret and