A Study of Block-based Medical Image Watermarking Using a Perceptual Similarity Metric

Birgit M. Planitz and Anthony J. Maeder

e-Health Research Centre, CSIRO ICT Centre
300 Adelaide St, Brisbane 4000, Queensland, Australia
Firstname.Surname@csiro.au

Abstract

Medical image watermarking has been proposed as an appropriate method for enhancing data security, content verification and numerical image fidelity. Due to the sensitive nature of the data, medical image watermarking requires that any additional information that is stored within an image must not affect the perceptual integrity of the image. In typical approaches, additional information is generally hidden in the entire image, or in the background regions of an image (so as not to affect the medical data). This paper presents a novel model whereby medical image regions are watermarked differently so that perceptual degradation due to watermarking is limited. The model partitions images into regions and characterises each region according to some feature(s). Each region is then watermarked with a particular watermark method and payload capacity such that perceptual degradation is limited. This paper presents the model in conceptual form and then uses one instance of it to demonstrate how it would be used in practise. Results on MR and CT images demonstrate that less visually sensitive areas on images can be watermarked using more robust techniques and more sensitive areas can be watermarked using lighter or no embedding.

1. Introduction

Image watermarking has become an increasingly popular research area with applications in data security, content verification and image integrity. Medical image watermarking is a particular subset of image watermarking whereby medical images are embedded with hidden information that may be used to assert ownership, increase the security, and verify the numerical integrity of medical images [1]. Unlike most images, medical images require particular care when embedding additional information within them because the additional information must not affect the reading of the images.

This paper presents a model that addresses this issue, by carefully analysing regions of medical images, categorising each region according to some feature and then watermarking each region differently such that only a limited amount of visual degradation occurs. Section 2 discusses the generic image watermarking encoding and decoding processes. Section 3 presents a review of current medical image watermarking methods. Section 4 outlines the new watermarking method that is based on a perceptual similarity metric. Section 5 then presents the results of this method for two medical image types of specific modality and physiology. Finally, Section 6 discusses future work and concludes the paper with summary remarks.

2. Background

Image watermarking consists of two processes: encoding and decoding. During encoding, a payload is embedded into an image, as shown in Figure 1. Typical payloads may be text (such as patient or image capture details), another image (such as a logo) or an identification number (such as patient or hospital identifiers).

Figure 1. Embedding a payload

Figure 2 shows the decoding process for a blind watermarking system. In this type of system only the embedded image is supplied from which the payload is to be extracted. Non-blind systems may have additional data such as the original image or payload.
3. Review

Medical image watermarking has not been the subject of as much research as generic image watermarking, however some methods have been designed that are specifically tailored for medical images. These methods are briefly reviewed here, with particular focus on the perceptual degradation caused to images. Each method is categorised according to robustness, namely fragile, robust or semi-fragile.

Fragile watermarking methods are designed such that the watermark is easily destroyed if the watermarked image is manipulated in the slightest manner. These methods generally cause the least perceptual degradation in images and are primarily used for image authentication. Fragile watermarks are often capable of localisation, and are used to determine where modifications were made to an image. Traditional methods embed checksums or pseudo-random sequences in the Least Significant Bit (LSB) plane [5]. More recent work has employed increasingly sophisticated embedding techniques such as cryptographic hash functions [8].

Fragile invertible authentication schemes have been proposed for medical images, whereby a watermark can be removed from a watermarked image, and the exact original image results [2,9]. Another medical image watermarking system embeds information in bit planes, which results in watermarked images with very low normalised root mean square errors (NRMSEs), indicating that the watermark is practically invisible [4]. A watermark that is embedded in the high frequency regions of an image has also been proposed, which also resulted in low NRMSEs [4].

Robust watermarks are designed to resist attempts to remove or destroy the watermark [8]. They are used primarily for copyright protection and content tracking. Many traditional robust methods are spread-spectrum, whereby the watermark is spread over a wide range of image frequencies [5]. More recent work includes the creation of image-adaptive watermarks, where parameters change depending on local image characteristics [8].

A number of robust medical image watermarking systems have been developed. For example one system uses a spread spectrum technique to encode copyright and patient information in images [13]. Another embeds a watermark in a spiral fashion around the Region of Interest (ROI) of an image [14]. Any image tampering that occurs will severely degrade the image quality. The Gabor transform has also been applied to hide information in medical images [6].

One observation that is generally applicable to robust systems is the greater the robustness of the watermark, the lower the image quality [7].

Semi-fragile watermarks combine the properties of both fragile and robust watermarks [8]. Like fragile methods, they are capable of localising regions of an image that are authentic and those that have been altered. Like robust methods, they can tolerate some degree of change to the watermarked image (for example, quantisation noise from lossy compression). Recent work in the area includes embedding a heavily quantised version of the raw image in the image, embedding key-dependent random patterns in blocks of the image, wavelet embedding, and embedding multiple watermarks [8].

Recently, much emphasis has been placed on semi-fragile medical image watermarking. Jagadish et al. investigated interleaving hidden information in the Discrete Cosine Transform (DCT) and the Discrete Wavelet Transform (DWT) domains [4]. DCT and DWT domains are widely studied because they relate to the JPEG and JPEG2000 compression methods respectively. The NRMSEs of encoding in these domains are higher than in the spatial and DFT domains, for the same amounts of information. Another example of embedding watermarks using DCT coefficients is presented in [12]. Multiple watermark embedding has also been used by a number of researchers [3,10,11]. Multiple watermarking systems have the advantages that different watermarks can be applied for different purposes (for example, copyright, authentication, data integrity) [3]. Also, image alterations can be detected by investigating the watermarks after the image has undergone manipulation or processing [10,11].

A variety of medical image watermarking methods have been presented in this section, with regard given to perceptual degradation caused by various method types. With exception to ROI watermarking, each of the above methods considers the degradation of the whole image, not specific image regions. This paper presents a new method where medical images are partitioned and each region of an image is watermarked such that the perceptual degradation caused by watermarking remains within a preset threshold.
4. Method

The aim of the watermarking system presented in this paper is to demonstrate that specific regions in medical images can be watermarked with specific watermarking methods and payload capacities, so that perceptual damage caused by watermarking is minimised.

The experiment relies on a number of important parameters:
1. image region size and shape
2. method of region characterisation
3. selection of appropriate watermarks and associated capacities (i.e. number of bits that are embedded per region)
4. method for comparing the visual similarity (or degradation) between raw and watermarked regions

The objective is to use the above to specify a set of regions, with specific characteristic values. Using this information, the most appropriate watermark method and capacity are selected for each region that falls within a specific range of characteristic values. The most appropriate refers to the most robust watermark method and highest capacity that can be embedded in the region such that the watermarked area falls within a preset allowable perceptual damage threshold. The watermarking system consists of two phases.

Phase I determines region characteristics, and appropriate watermarks for each region type, as shown in Figure 3. The output of Phase I is a table that specifies the most appropriate watermark (WM) method and payload capacity for each range of region characteristic values.

Phase II encodes (Figure 4) and decodes (Figure 5) watermark payloads into and from medical images, using the watermark selection table.

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4.1 Method and Capacity Specification

Phases I and II are described in greater detail in the following subsections. Section 5 also contains two subsections where the results of the current implementations of Phases I and II are presented.
watermarking system. The parameter and threshold choices are discussed in greater detail below.

Regions are constructed from 8x8 pixel blocks, as this size is commonly used in other image operations where perceptual changes are involved, such as JPEG compression. Note that one of the watermark methods is based on DCT, which is robust against small levels of lossy compression.

Parameter and Threshold choices are discussed in greater detail below.

Regions are constructed from 8x8 pixel blocks, as this size is commonly used in other image operations where perceptual changes are involved, such as JPEG compression. Note that one of the watermark methods is based on DCT, which is robust against small levels of lossy compression.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Current Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>region - shape</td>
<td>square blocks</td>
</tr>
<tr>
<td>- size</td>
<td>8x8 pixels</td>
</tr>
<tr>
<td>region characterisation</td>
<td>σ_R - standard deviation</td>
</tr>
<tr>
<td>watermark methods and payload capacities</td>
<td>DCT2 - DCT with 2 bits per block</td>
</tr>
<tr>
<td></td>
<td>DCT1 - DCT with 1 bit per block</td>
</tr>
<tr>
<td></td>
<td>LSB2 - LSB with 2 bits per block</td>
</tr>
<tr>
<td></td>
<td>LSB1 - LSB with 1 bit per block</td>
</tr>
<tr>
<td>perceptual similarity</td>
<td>SC - structural comparison</td>
</tr>
<tr>
<td>- metric</td>
<td>SC ≥ 0.9999 or SC ≥ 0.999</td>
</tr>
<tr>
<td>- threshold</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Parameter selections for watermarking system

Regions are characterised using ranges of standard deviation (σ_R is the standard deviation of a region R). Standard deviation gives an indication of the uniformity/non-uniformity of a region. Each region on a 12-bit greyscale medical image falls into one of the following six ranges, where σ_min and σ_max are the lower and upper bounds respectively.

<table>
<thead>
<tr>
<th>Region</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ_min</td>
<td>2^0</td>
<td>2^1</td>
<td>2^2</td>
<td>2^3</td>
<td>2^4</td>
<td>2^5</td>
</tr>
<tr>
<td>σ_max</td>
<td>2^1</td>
<td>2^2</td>
<td>2^3</td>
<td>2^4</td>
<td>2^5</td>
<td>2^6</td>
</tr>
</tbody>
</table>

Table 2. Ranges of region characterisation values

Non-linear categories are used, because standard deviation is related to the perceptual metric presented later in this section. It will be shown that, the higher the standard deviation, the smaller the image degradation caused by watermarking, hence the greater ranges for higher σ values.

Two watermark methods have been selected, LSB and DCT. LSB was selected for sensitive image regions, as it is known to cause minimal perceptual degradation. The DCT method was selected as a more robust watermarking choice and is based on an existing algorithm [11]. Very light capacities have been selected, one or two bits per region, again to minimise perceptual damage caused to a region.

The perceptual metric that was selected for this operation is the structural comparison SC metric, which is an integral component of the structural similarity index measure [15]. SC has been selected because it compares the structural similarity of raw and watermarked regions. Structural similarity is an essential factor when considering differences in images that are detected by the human visual system [15]. SC is related to standard deviation, and is given by:

\[ SC(x, y) = \frac{\sigma_{xy} + K}{\sigma_x \sigma_y + K} \]

where \( \sigma_x \) and \( \sigma_y \) are the standard deviations of regions x and y respectively, \( \sigma_{xy} \) is the estimated correlation coefficient and K is a small constant to map SC to a convenient range [-1,1]. Figure 6 shows a typical curve of SC versus \( \sigma_x \), where SC quickly approaches a maximum of value of 1 for high standard deviations.

Figure 6. Behaviour of SC with respect to standard deviation

Two alternative thresholds close to 1 have been specified to determine the amount of visual similarity that must exist between image regions. The first allows for almost no visual degradation, \( SC \geq 0.9999 \). The second is \( SC \geq 0.999 \), allowing for slightly more degradation. The most appropriate watermark method and capacity can be determined for each region type using either threshold, depending on the level of perceptual similarity required.

The final outcome of Phase I is a table that specifies the most appropriate watermark method and payload capacity for each standard deviation range. An example of such a table is presented in Section 5.1. The following section discusses how the table is incorporated into the watermark encoding and decoding systems.

4.2 Encoding and Decoding

This section presents Phase II of the watermarking system: the encoder and decoder. It also discusses some issues that may arise with the region-based watermarking approach.

The watermarking encoder performs the following:

1. divide the raw image into 8x8 blocks
2. for each block:
   a) compute \( \sigma_x \)
b) use Phase I results (the WM selection table) to obtain the most appropriate watermark method and capacity for that region
c) watermark the region with a section of the payload

To extract the watermark, the following procedure is used:

1. divide the watermarked image into 8x8 blocks
2. for each block:
   a) compute $\sigma_R$
   b) use Phase I results (the WM selection table) to obtain the most appropriate watermark method and capacity for that region
   c) extract section of the payload from the region

A key issue that arises with this watermarking method is the possibility that regions may not be characterised in the same standard deviation range before and after watermarking. The decoding method is only acceptable if the number of falsely decoded regions is small. Experimental results of this and other issues are presented in the following section.

5. Results

Different types of medical images have been watermarked using the two phases of the watermarking system, which were presented in Sections 4.1 and 4.2. The outcomes of the data gathering stage of Phase I and the encoding/decoding stages of Phase II are presented in Sections 5.1 and 5.2 respectively. This section also considers the option of increasing payload capacity of medical images, by watermarking both the high standard deviation regions and the background regions of the images.

5.1 Method and Capacity Specification

In the current implementation of Phase I, test regions were generated that are typical of those found on 12-bit greyscale medical images. The test regions were categorised into the six standard deviation ranges outlined in Table 2, and the most appropriate watermark method and capacity for each range were determined. This section discusses how the test regions were generated and how the method and capacity for each region range were selected.

The test regions were 8x8 image blocks that are representative of 12-bit greyscale medical images. Blocks were created by randomly assigning pixel intensities with standard deviations that fall into the six standard deviation categories. 10000 sample blocks were created for each standard deviation range, to cover a wide variety of options.

Each block was watermarked using the four preset methods and capacities: DCT2, DCT1, LSB2 and LSB1. For each watermarking method and capacity, the raw and watermarked regions were compared using the structural comparison metric. The minimum (worst) $SC$ value for each standard deviation range is shown in Table 3.

<table>
<thead>
<tr>
<th>$\sigma_{\text{min}}$</th>
<th>0</th>
<th>2</th>
<th>2$^2$</th>
<th>2$^3$</th>
<th>2$^4$</th>
<th>2$^5$</th>
<th>2$^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCT 2</td>
<td>.9951</td>
<td>.9979</td>
<td>.9993</td>
<td>.9996</td>
<td>.9998</td>
<td>.9999</td>
<td></td>
</tr>
<tr>
<td>DCT 1</td>
<td>.9966</td>
<td>.9983</td>
<td>.9993</td>
<td>.9996</td>
<td>.9999</td>
<td>.9999</td>
<td></td>
</tr>
<tr>
<td>LSB 2</td>
<td>.9984</td>
<td>.9990</td>
<td>.9995</td>
<td>.9998</td>
<td>1.000</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>LSB 1</td>
<td>.9996</td>
<td>.9995</td>
<td>.9999</td>
<td>1.000</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Selection table for watermarking method and payload capacity for $\sigma$ ranges

Table 3 shows that as the standard deviation of a region increases, the perceptual similarity also increases for every watermark method and capacity. The table also reaffirms that DCT embedding produces more perceptual error than LSB embedding according to the $SC$ criteria, and that higher capacities also produce greater visual degradation.

Table 3 is the resultant WM selection table of Phase I, which can be used to select the optimal watermark method and capacity for specific image region types. For example, the dark shaded areas show which methods and capacities may be used if all image regions must have a perceptual similarity $SC \geq 0.9999$ (when comparing the raw and watermarked regions). The light and dark shaded regions show which methods are permitted for a perceptual threshold $SC \geq 0.999$. If more than one method and capacity can be used per region, the one that can embed the greatest amount of information, and is most robust is selected. For example, DCT with 2 changed bits per block is allowed for ranges $\sigma_{R} \geq 2^6$ that have perceptual similarities $SC \geq 0.9999$.

Table 3 was created using experimentally generated blocks of random pixels. It was essential to determine whether the test regions are indicative of actual medical image regions. That is, 8x8 medical image blocks must produce $SC$ values that are greater than the minimum values outlined for Table 3 to be used as the WM selection table.

Two specific types of medical images were used for initial experimentation: MRI head scans and CT chest images. An example of each is shown in Figure 7.
Figure 7. Examples of (a) MR head and (b) CT chest images

For each image type, 20 test images were selected. These images were divided into regions, and the regions were categorised using the six standard deviation ranges. The regions were then watermarked using each of the four possible method/capacity combinations and the structural comparison was computed. Every SC value that was lower than the minimum values specified in Table 3 was noted.

The outcomes of the experiment indicated that all regions with $\sigma_R \geq 2^2$ result in perceptual errors that are larger than the preset minimums of Table 3. This indicates that Table 3 can be used as a WM selection table when selecting the optimal watermark method and capacity for regions with $\sigma_R \geq 2^2$. An exception to this statement is $\sigma_R < 2^2$. For both types of medical images, cases existed where SC values were lower than preset thresholds, for this standard deviation range. This is not a critical issue however, as these regions generally should not be watermarked. This is because watermarking in this standard deviation range causes the greatest errors when comparing the raw and watermarked regions using the SC metric.

In summary, Table 3 can be used as a WM selection table for standard deviation ranges where $\sigma_R \geq 2^2$. Also, blocks with $\sigma_R < 2^2$ should not be watermarked due to the low SC values that result.

5.2 Encoding and Decoding

The most appropriate watermark method and capacity that resulted for each region type in Table 3 is shown in Table 4.

Using Table 4, successive sections of a given payload can be encoded into specific regions in a medical image. As discussed in Section 4.2, the most important issue that arises from region-based watermarking is that image regions might not be categorised in the same standard deviation ranges before and after watermarking. To test the number of occurrences where this issue holds true, the following experiment was conducted.

<table>
<thead>
<tr>
<th>$\sigma_{\text{min}}$</th>
<th>0</th>
<th>$2^1$</th>
<th>$2^2$</th>
<th>$2^3$</th>
<th>$2^4$</th>
<th>$2^5$</th>
<th>$2^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{\text{max}}$</td>
<td>$2^1$</td>
<td>$2^2$</td>
<td>$2^3$</td>
<td>$2^4$</td>
<td>$2^5$</td>
<td>$2^6$</td>
<td>$2^7$</td>
</tr>
<tr>
<td>SC 20.9999</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>LSB1</td>
<td>DCT1</td>
<td>DCT2</td>
<td>DCT2</td>
</tr>
<tr>
<td>SC 20.9999</td>
<td>-</td>
<td>LSB2</td>
<td>DCT2</td>
<td>DCT2</td>
<td>DCT2</td>
<td>DCT2</td>
<td>DCT2</td>
</tr>
</tbody>
</table>

Table 4. Methods and capacities used for specific perceptual limits

Twenty MR and twenty CT test images were again selected for the experiment. Each set of images was partitioned into blocks. All the blocks in each of the six standard deviation ranges were watermarked using Table 4 results. The watermarked blocks were then re-categorised into one of the six standard deviation ranges. If the new standard deviation range was not the same as the raw, the result was noted. Table 5 shows the percentage of regions in each category that were not categorised in the same range before and after watermarking.

<table>
<thead>
<tr>
<th>$\sigma_{\text{min}}$</th>
<th>22</th>
<th>$2^3$</th>
<th>$2^4$</th>
<th>$2^5$</th>
<th>$2^6$</th>
<th>$2^7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{\text{max}}$</td>
<td>$2^3$</td>
<td>$2^4$</td>
<td>$2^5$</td>
<td>$2^6$</td>
<td>$2^7$</td>
<td>$2^8$</td>
</tr>
<tr>
<td>SC 20.9999</td>
<td>-</td>
<td>-</td>
<td>.0723</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CT 20.9999</td>
<td>-</td>
<td>-</td>
<td>.0609</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SC 20.9999</td>
<td>.4167</td>
<td>.0775</td>
<td>.0723</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CT 20.9999</td>
<td>.2958</td>
<td>.0873</td>
<td>.0380</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5. Percentages of incorrectly classified regions

The outcomes of Table 5 show that lower standard deviation ranges produce greater errors than higher ranges. This is to be expected, because the lower the initial standard deviation range, the greater the chance that a block will be categorised differently after watermarking. This is due to the fact that changes are more noticeable at lower standard deviations when using the SC metric.

It is worth noting that only a very small percentage of regions actually fall out of range. However, if payloads must be exactly equal before and after watermarking, higher standard deviation ranges ($\sigma_R \geq 2^5$) are recommended for images that are similar to the test images used in the experiments presented in this paper.

The maximum amount of damage caused to a watermark for each of the twenty images in each image type is listed in Table 6. The maximum damage caused is very small <1% of the watermark, indicating that it is feasible to watermark all regions specified in Table 4, provided an exact copy of the raw payload is not required at the output. This could be used for payloads such as logos, where original information is...
not as sensitive as text such as patient identification numbers.

<table>
<thead>
<tr>
<th>Test Image</th>
<th>Capacity (# bits)</th>
<th>Maximum Capacity (# bits)</th>
<th>Regions Watermarked (% bits)</th>
<th>Watermark Damaged (% bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.20.9999</td>
<td>632</td>
<td>2048</td>
<td>30.86</td>
<td>.1582</td>
</tr>
<tr>
<td>MR1</td>
<td>3987</td>
<td>8192</td>
<td>48.67</td>
<td>.1254</td>
</tr>
<tr>
<td>SC.20.9999</td>
<td>1922</td>
<td>2048</td>
<td>93.85</td>
<td>.5203</td>
</tr>
<tr>
<td>CT1</td>
<td>6548</td>
<td>8192</td>
<td>79.93</td>
<td>.1680</td>
</tr>
</tbody>
</table>

Table 6. Percentage of watermark damaged through extraction process

An interesting point that is shown in Table 6 is the actual watermarking capacity of each image. The four test images that were used to generate the table are very different in terms of intensity ranges in regions, as demonstrated in Figure 8. The watermarking system favours images with many regions that have high standard deviations. One alternative method is to watermark the background as well as the high standard deviation foreground regions of medical images. Note that background regions are generally ignored by the current implementation of the watermarking system, because they have low standard deviations.

<table>
<thead>
<tr>
<th>Test Image</th>
<th>Capacity without background (% bits)</th>
<th>Capacity with background (% bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.20.9999</td>
<td>30.86</td>
<td>85.45</td>
</tr>
<tr>
<td>MR1</td>
<td>48.67</td>
<td>67.71</td>
</tr>
<tr>
<td>CT1</td>
<td>93.85</td>
<td>100</td>
</tr>
<tr>
<td>SC.20.9999</td>
<td>79.93</td>
<td>99.95</td>
</tr>
</tbody>
</table>

Table 7. Watermark capacity with and without watermarking the background

Table 7 shows that the watermarking system presented in this paper favours medical images that have regions with high standard deviations and/or large background areas. These areas cause the least perceptual damage when watermarked and are also able capable of carrying larger sections of a payload.

6. Future Work and Conclusions

This paper presented a medical image watermarking model whereby medical image data is used to determine the most appropriate watermark method and capacity for each region on a medical image. The model was invented to preserve the visual integrity of medical images, which must not be compromised by watermarking. It was shown that although numerous medical image watermarking methods exist, the degradation of the whole image rather than of individual subsections is generally considered. ROI based techniques do not consider the degradation of all regions, only of non-ROI regions. ROI regions generally remain unwatermarked and therefore unprotected.

The model presented in this paper considers the most appropriate watermark method and capacity for each 8x8 block in a medical image. It was shown that using the structural comparison metric, less perceptual damage is caused to areas of high standard deviation than low standard deviations. Therefore, regions of high standard deviation on medical images can be watermarked with more robust methods and at higher capacities than regions with lower standard deviations. Higher standard deviation regions also fall into the same standard deviation category before and after watermarking, because they remain unaffected by the payload information that is embedded within them.

One area on that was neglected by the watermarking model presented here is the black background, which generally has a very small standard deviation. In addition to watermarking high standard deviation areas on medical images, background regions can also be
watermarked to increase the payload capacity of the images. This can be regarded as a special case of ROI.

Some future options that can be explored for the medical image watermarking model are:

- alternative region definitions, other than 8x8 blocks
- more sophisticated region characterisations, tailored to medical images (for example, segmentation into different tissue types)
- other perceptual similarity, or error, metrics (for example, ones that take luminance and contrast into account)

This type of system is appropriate for medical images because the amount of perceptual degradation caused by watermarking is limited. At the same time medical image data is protected by watermarking, which enhances the security of the data.

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7. References


