

### Citation for published version

Fallahpour, M.; Megías, D.; Ghanbari, M. (2011). Reversible and high capacity data hiding in medical images. IET Image Processing, 5(2), pp. 190-197.

### DOI

<https://doi.org/10.1049/iet-ipr.2009.0226>

### Document Version

This is the Submitted Manuscript version.

The version in the Universitat Oberta de Catalunya institutional repository, O2 may differ from the final published version.

### Copyright and Reuse

This manuscript version is made available under the terms of the Creative Commons Attribution Non Commercial No Derivatives licence (CC-BY-NC-ND)

<https://creativecommons.org/licenses/by-nc-nd/2.5/es/>, which permits others to download it and share it with others as long as they credit you, but they can't change it in any way or use them commercially.

### Enquiries

If you believe this document infringes copyright, please contact the Research Team at: [repositori@uoc.edu](mailto:repositori@uoc.edu)



# Reversible and high capacity data hiding in medical images

M. Fallahpour, D. Megias and M. Ghanbari

## Abstract

In this paper we introduce a highly efficient reversible data hiding system. It is based on dividing the image into tiles and shifting the histograms of each image tile between its minimum and maximum frequency. Data are then inserted at the pixel level with the largest frequency to maximize data hiding capacity. It exploits the special properties of medical images, where the histogram of their non-overlapping image tiles mostly peak around some gray values and the rest of the spectrum is mainly empty. The zeros (or minima) and peaks (maxima) of the histograms of the image tiles are then relocated to embed the data. The grey values of some pixels are therefore modified.

High capacity, high fidelity, reversibility and multiple data insertions are the key requirements of data hiding in medical images. We show how histograms of image tiles of medical images can be exploited to achieve these requirements. Compared with data hiding method applied to the whole image, our scheme can result in 30%-200% capacity improvement and still with better image quality, depending on the medical image content. Additional advantages of the proposed method include hiding data in the regions of non-interest and better exploitation of spatial masking.

Key words: data hiding, Image watermark, medical images

## 1. Introduction

Data hiding is the insertion of a message, also called content, watermark or embedded message, into a host document or cover media. It is required that the embedded information remains hidden to any unauthorized user. Non-interfering with the marked document and its integrity and authentication to any attempt to suppress it are also the key requirements [1].

In applications where additional information is required to describe another information media, such process can be very useful. For instance, in medical images, patients' details and the doctors' views can be inserted into the medical images to form a comprehensive data bank. The integrity of such a

concentrated database, not only makes medical files very secure, but also their remote access by fellow doctors is also possible. However, data hiding in medical images, due to their specific requirements impose certain constraints, which set some specific requirements. First, medical images are required to be of high quality and hence the embedded data should be invisible. Second, data insertion may be gradually introduced. Indeed, during the creation of a medical file, it is undeniable to question the patient on his/her personal, family, social life and family conditions. As the patients get more acquainted with their doctors, or quires arise, the new information comes to be added to constitute a medical history of the patient. Moreover, the fellow doctors may also add their own observations. This necessitates frequent addition/insertion of medical information to the main file. Thus not only the data hiding system has to be reversible, the capacity of the medical file is required to accommodate all information necessary for the doctor such as the identification of the patient, his administrative information and the medical database [2]. Thus high quality (fidelity), authentication, high capacity, frequent insertions and reversibility are the main requirements of medical files.

In the past two decades a variety of data hiding schemes that can meet the above requirements have been proposed and applied to medical images. Various kinds of data hiding for medical images that may meet some but not all the requirements can be categorized into three requirements of high quality, reversibility and high capacity.

To preserve high quality, one may embed information in the region of non-interest (RONI) [3], [4]. The main drawback of this method is the ease of introducing copy attack on the non-watermarked regions. Various experiments suggest that RONI corresponds in general to the black background of the image, but sometimes RONI can include gray-level parts of little interest [5], thus leaving some area for embedding on the gray level image itself. For the reason that there is no interference with the invisibility, image content is less strict; consequently one can revert to methods with higher robustness and capacity [3]. Another medical image watermarking system embeds information in bit planes, which results in stego images with very low normalized root mean squared errors (NRMSE), indicating that the watermark is practically invisible [6]. A watermark that is embedded in the high frequency regions of an image has also been proposed, which also resulted in low NRMSEs [6].

On the reversible data hiding, where the embedded content can be added or removed without affecting the original image quality, [7], a vast attempt has been recently provided. However the capacity is still way below the embedding capacity of nonreversible data hiding technique. However, if

capacity is of prime importance, then quality can be sacrificed for capacity. For instance, the embedded data may replace some image details such as the least significant bit of the image [8] or details are lost after lossy image compression [9]. For a survey on medical watermarking application, the readers may refer to [10].

Perhaps the histogram-shifted-based lossless data hiding algorithm proposed by Ni et al. [11] is one of the most capacity efficient data hiding system that suits medical images well. Since in this method, at most the intensity of all the watermarked pixels are shifted by one quantum level, then for an 8-bit image with the mean squared error (MSE) of 1, the PSNR of the watermarked image, at worst is  $PSNR=10 \times \log_{10}(255 \times 255 / MSE) = 48.13 \text{ dB}$ , which is regarded a very high quality and is suitable for medical images. Recently Lin et al. [12] suggested a high capacity and low distortion algorithm based on differences between the neighbouring pixels. Tsai et al. [13] with a predictive coding algorithm propose a technique which improves Ni et al. [11] for some images by about 1.5 dB. However performance of their method is image content dependent and for some images at the same capacity, the quality is poorer than [11].

In this paper we show how by applying shifted-histogram on the tiled images, not only the watermarked image quality can be improved, but more importantly, the data hiding payload can be significantly increased. Other advantages of the proposed system include; data hiding on the regions of non-interest and capacity -quality trade off.

The rest of the paper is organised as follows. Characteristics of the proposed algorithm and its details are described in Section 2. Experimental results are presented in Section 3, and conclusions are drawn in Sections 4.

## 2. Proposed method

The main idea in the shifted-histogram data hiding method is to find a pair of maxima and minima in the image pixel intensity histogram and then shift the intensity of those pixels within the max and min frequency range by one level, towards the minimum frequency level. This creates an empty space on the shifted histogram at the vicinity of the maximum pixel density. To embed a data stream, the modified image is re-scanned and when the pixel of maximum frequency is encountered if the corresponding bit in the embedding stream is "1" its gray level is incremented by one level otherwise it is unaltered. Thus the maximum number of bits that can be hidden into the image is equal to the

maximum frequency of the histogram. Due to the created gap, the data hiding mechanism (watermarking) is reversible. The values of the pixels with maximum and minimum frequency are also recorded as side information. If the minimum frequency is non-zero, then their numbers also need to be embedded as the side information, which reduces the data hiding capacity of the system.

Although Ni et al. have shown that their algorithm for a vast variety of images outperforms almost all the known reversible data hiding methods so far, we believe for medical images it has two drawbacks:

1. If the intensity of the pixels in a region of interest lay in the maximum and minimum range of the histogram, then their values are also modified.
2. If the minimum frequency of the histogram is non-zero, the positions of all the pixels with minimum frequency have to be embedded as side information. This restricts the data hiding capacity of the system.

Now if the image is partitioned into sub-images, the so-called image tiles, and the histogram shifting is applied to each image tile, not only the above shortfalls are overcome, but some additional benefits can be gained. These include:

- 1) Region of non-Interest (RONI): The image can be divided into parts such that, the histograms of image tiles that contain region of interest, are not modified.
- 2) High payload: In the shifted-histogram based data hiding method, the maximum number of hidden bits (watermark signature) is equal to the maximum frequency of the pixel intensity histogram. When the histograms of the image tiles are considered separately, it is intuitive that the sum of individual maxima is greater than the maximum of the original image intensity histogram. Hence shifted-histograms of the image tiles can hide more watermark data.
- 3) Higher objective quality: In the shifted-histogram method, the marked image quality depends on the number of pixels whose intensity lay between the maximum and minimum frequency pixel values, irrespective of the number of hidden bits. That is, image quality due to embedding of one bit of data is as bad/good as if the maximum payload (equivalent to the maximum frequency of the intensity histogram) is embedded. On the other hand, with the histograms of image tiles, they may be first prioritized, in the order of their least intensity distance between the maximum and minimum frequency. Data are embedded in the ordered image tiles till it is fully loaded, and the left over data

will be carried over to the next image tile, and so on. In this way, for a given payload, the intensity of the smallest number of pixels is modified and hence image quality will be at its best.

- 4) Higher subjective quality: Rather than prioritizing the image tiles as in 3 above, they may be prioritized based on their spatial content. Data hiding can then start from those image tiles that have the highest spatial details. In this case, due to spatial masking of the human visual system, the subjective quality of the watermarked image will be at its best.
- 5) Narrower histogram: Some image tiles have much narrower histograms than that of the whole image. This is particularly true for medical images that leads to the following useful properties for data hiding:
  - a. In the broader histogram of the whole image the minimum frequency may not be zero. Hence for reversible data hiding, their positions need to be identified and given as side information, which greatly reduce the data hiding capacity. On the other hand, in the narrower histograms of the image tiles, the minimum frequencies are more likely to be zero.
  - b. Narrower histograms provide the opportunities of selecting the most suitable pairs of peaks-zeros that will increase the quality of the marked images.

Through the experiments we will verify these claims.

It should be noted that selection of the (peak, zero) pairs has an important impact on the data hiding strategy. While the maximum frequency increases the data hiding capacity, the distance between the peak and zero frequency affects the image quality. Hence capacity may be traded for quality, and vice versa. Also, to increase the capacity, more than one pairs of (peak, zero) pixels may be used. In this case, for reversibility, the intensity of some pixels may have to be shifted by more than one level. Of course selection of the (peak, zero) pairs, will greatly affect the quality and hence they should be selected with great care. For example in Figure 1, which is the histogram of a human chest, there are two peaks at the pixel intensities of 18 and 236 with frequency peaks of  $h(18)$  and  $h(236)$ , and several zeros and at least four at levels of 0, 1, 254 and 255 with frequencies of  $h(0)$ ,  $h(1)$ ,  $h(254)$  and  $h(255)$ . If the two left zeros of frequencies  $h(0)$  and  $h(1)$  are selected respectively for the corresponding peaks of frequencies  $h(18)$  and  $h(236)$ , then the gray values of the pixels between 18 and 236 must be decreased by 1 and the values between 1 and 18 must be decreased by 2. For this

picture, with 512 x 512 pixels resolution, this will modify 241749 pixels, and the PSNR will be 47.39 dB. If the right hand side zeros are selected, i.e., at pixel values of 254 and 255, the gray values of the pixels between 18 and 254 must be increased by 1 and the values between 236 and 255 must be increased by 2. This will modify 239167 pixels and the PSNR will be 47.56 dB. However, if the pairs of  $h(236)$  and  $h(254)$  are selected as the first pairs and  $h(0)$  and  $h(18)$  as the second pairs, the gray values of the pixels between 1 and 18 must be decreased by 1 and gray values between 236 and 254 must be increased by 1. Thus the gray values of only 43372 pixels need to be modified and the PSNR will be 55.97 dB. Therefore, proper selection of the (peak, zero) pairs will significantly affect the image quality.

The two steps of our embedding of watermark and its detection are as follows:

#### A. Embedding:

- 1) The image is first divided into  $N_b$  non-overlapping image tiles (e.g.  $N_b = 4, 16$ ). The intensity histogram of each image tile is generated and, the following steps (2-4) are iteratively executed for each image tile.
- 2) In each image tile, for a given number of  $n$  (peak, zero) pairs, the pairs are chosen such that the image quality is either maximized (least picture intensity distances between the chosen pairs), or according to any other criteria such as perceptual quality. The  $(p_i, z_i)$  pairs are then prioritized either based on objective or subjective quality, as explained above, with  $p_i$  as the intensity of the  $i^{th}$  peak and  $z_i$  as the intensity of the  $i^{th}$  zero.
- 3) The following iterations are executed  $n$  times for  $i = 1 : n$ .
- 4) For pair  $(p_i, z_i)$  the image tile is scanned and if:
  - a)  $p_i > z_i$ , the gray values of the pixels between  $z_i + 1$  and  $p_i$  are reduced by one (shifting the range of the histogram  $[z_i + 1, p_i]$  by 1 to the left). This creates a gap at gray level  $p_i$ . The image tile is re-scanned and the values of the pixels with gray value of  $p_i - 1$  are incremented by one if the corresponding secret bits are "1" otherwise they will not be modified.

b)  $z_i > p_i$ , the gray values of the pixels between  $p_i + 1$  and  $z_i - 1$  are incremented by one. This creates a gap at gray value  $p_i + 1$ . Then image tile is re-scanned and the values of the pixels with gray value of  $p_i$  are increased by one if the corresponding bits of to be embedded data are "1", otherwise they will not be altered.

The number of image tiles,  $N_b$ , their priority order, number of (peak, zero) pairs  $n$ , and their positions will be treated as side information that needs to be transmitted to the receiving side for data retrieval.

### *B. Detection:*

For the given  $N_b$ , their embedding order and  $n$ , the following steps are followed to extract the secret message from a marked image and the lossless recovery of the host image.

1) Firstly, the image is divided into  $N_b$  image tiles. They are then rank ordered in their order of priority. Then steps 2-3 are repeatedly executed for each image tile.

2) The following iterations are carried out  $n$  times for  $i = 1 : n$ .

3) For pair  $(p_i, z_i)$  the image tile is scanned and if:

a)  $p_i > z_i$ , the pixel with gray value  $p_i$  indicates that the embedded data bit was 1 and it should not be modified. However, if the gray value of current pixel is equal to  $p_i - 1$ , it indicates that the embedded data bit was 0. In this case, its gray value has to be increased by 1. Later on the gray values of all pixels with gray values between  $z_i$  and  $p_i - 2$  need to be increased by one.

b)  $z_i > p_i$ , the pixel with gray value  $p_i$  indicates that the embedded data bit was 0 and they do not need to be modified. However, if the gray value of current pixel is equal to  $p_i + 1$ , it indicates the embedded data bit was 1. Then, its gray value is reduced by 1. Therefore, the gray values of all pixels with gray values between  $p_i + 2$  and  $z_i$  are reduced by 1.

The shift of the peaks and zeros should not lead to loss of information about the location(s) of peaks and zeros. It is noteworthy that, in any case, if there are not sufficient number of zeros the minima are used instead of zeros. In this case, values of minima are sent as side information.

### *Theoretical analysis of capacity and PSNR*



In the shifted-histogram-based algorithm, the data hiding capacity depends on the value of the peak of the histogram frequency,  $h(p)$  and the quality is determined by the number of pixels whose values between the peak  $p$  and zero  $z$  will be shifted. Now if the image is divided into  $N_b$  tiles and in each time the frequency of the pixel corresponding to the whole image peak,  $p$ , is taken as the image tile peak, and with the same position of zero,  $z$ , then both the capacity and image quality of the tiled image will be the same as the whole image. However, each tile may have a new peak in its histogram  $h_i(p_i)$  at pixel position  $p_i$ , then for all tiles:

$$h_i(p) \leq h_i(p_i) \quad (i = 1 \text{ to } N_b)$$

$$h(p) = \sum_{i=1}^{N_b} h_i(p) \leq \sum_{i=1}^{N_b} h_i(p_i) \quad (1)$$

Therefore, equation (1) shows that embedding in each image tile separately improves the data hiding capacity. Equality holds only if the peaks in the individual tiles are the distributed peak of the whole image, which is rare to happen. Thus by image tiling the data hiding capacity is improved.

On the minimum of histogram with  $h_i(z_i)$  as the frequency of zero point in the  $i^{th}$  tile and  $h_i(z)$  as the frequency of zero point of whole image in  $i^{th}$  tile ( $i=1$  to  $N_b$ ), then the followings are held:

$$h_i(z_i) \leq h_i(z) \quad (i = 1 \text{ to } N_b)$$

$$\sum_{i=1}^{N_b} h_i(z_i) \leq \sum_{i=1}^{N_b} h_i(z)$$

$$\sum_{i=1}^{N_b} h_i(z_i) \leq h(z) \quad (2)$$

Equation (2) implies that even if  $h(z)$  of the whole image may not be zero, in several image tiles, there are numerous candidates  $z_i$ , with  $h_i(z_i) = 0$ . This not only reduces the data hiding overhead, improving the capacity, but also makes it possible to select zeros very close to the main peak, to cause minimum number of shifted pixels, hence improving the quality. Moreover, since according to (1) under image tiling the capacity is improved, then for some image tiles, the closest semipeak (not the main peak) may be chosen to trade capacity for quality. Finally, for some image tiles, several pairs of peak-zero can be selected, to improve capacity, without having side effect on quality. These are all in addition to the Region of Non-interest data hiding ability that image tiling can offer.

### 3. Experimental results and evaluations

We have implemented and compared the performance of algorithms in [11], [12] and [13] with our proposed method (for 4 and 16 image tiles) on a variety of medical images. The original image sizes were 512 x512 pixels with 8 bit resolution. In the following, results of the experiments to verify the advantages and properties of image tiles versus the whole image are presented.

#### *3.1 Narrower distribution:*

Fig. 2-a shows the whole image of a Cancer tissue and its fully marked (Fig 2-b) with two pairs of peak-zero along with its histogram in Fig 2-c. In this broad spectrum, the two peaks of the histogram have the capability of hiding 6492 bits of data, resulting in marked image quality of 44.6 dB, with almost non-perceptual artefacts.

On the other hand, Fig 3 shows 4 tiles of this image, with their shifted histograms. Similar to the whole image, in each of these image tiles, two pairs of peak-zero are used with the data embedding capacity of 4362, 3794, 4217 and 1874 bits/image tile for Figs 3-a to Fig 3-d, respectively. The narrower spectra of Fig 3-a and Fig 3-c result in large capacity of 4362 and 4217 bits, compared to that of Fig 3-d, with wider spectrum that only accommodates 1874 bits. Moreover their watermarked quality is 48, 42.22, 45.26 and 49.06 dB respectively, which indicate, due to narrower spectra of fig3-a and fig3-c over fig3-b, although their capacity are almost equal, but their quality is much better. However the overall capacity of 4-tile image is 14,247 bits, which is almost 119% extra payload compared to the whole image of Fig 2 and the average marked image quality of 45.3 dB, or 0.7 dB improvement in quality. These figures indicate that the image tile pixel intensity histograms have the property of hiding more data in one image tile than the other. Moreover, the number of peak-zero pairs can vary from one tile to another and they can be arranged such that for instance, the watermarked image quality is uniform across the whole image.

#### *3.2 Higher capacity and quality:*

Table 1 shows the maximum payload and the quality of 10 various medical images which are shown in Fig 4, for shifted histograms of whole, 4-tile and 16-tile versions. For simplicity they are respectively identified as WSH, TSH-4 and TSH-16. In each experiment the results were the average of 60

embedded sets of random bit stream messages, generated by the random number generator of `random()` of MATLAB. In each experiment, data were embedded at the full capacity of each image, without use of any priority in image tiles, their spectral density or number of peak-zero pairs. Up to 4 pairs of peak-zero have been used but the PSNR may not be acceptable at some larger number of pairs.

The first column shows the number of peak-zero pairs and the maximum payload of the whole image, 4-tile and 16-tile images are respectively depicted in columns, 2, 3 and 5. The percentage of increase in payload for 4 and 16 tile images over the whole image, for similar number of peak-zero pairs are respectively shown in columns 4 and 6. Finally, the watermarked quality of each method is shown in columns 7, 8 and 9. Marked image quality greater than 40 dB are highlighted.

As the table shows, tiled images have higher data hiding capability and still do have a better watermarked image quality. The improvement in payload capacity is image dependent. For example, in Image number 10 (Im10), which shows the least average percentage of improvement in capacity of 1-5 % for 4-tile and 30-40% improvement for the 16 tile images over the whole image, the watermarked image quality under tiling is always better than the whole image itself. On the other hand, in image 5 (Im5), the 4-tile and 16 tile images can hide on average more than 100% and 100-220% respectively of data over the whole image, albeit at a slightly lower quality. The degree of improvement in payload varies with marked image quality, as in all cases quality can be traded for capacity. For equal quality, the improvement in payload capacity can be better judged from Fig 5, for two extreme images of Im5 and Im10. For instance for a 42 dB image quality, in Im10 while 4-tile image has 8% larger capacity over the whole image, in 16-tile version, this extra capacity is about 48%. This extra capacity, for the most favourable image, Im5 of the above data base is 155% and 275% for the 4tile and 16-tile images respectively.

### *3.3 region of non-interest (RONI)*

A major weakness of shifted spectrum on the whole image is that, hidden data can affect regions of interest and non-interest equally. On the other hand, spectra of image tiles are independent from each other, and can be treated differently. For example, tiling the MRI image of Fig 6-e into 16 segments, the 4 corner tiles of 1, 4, 13 and 16 (tiles are numbered in the scan order from left to right and top to bottom), shown in Fig6 a-d, can be chosen for data hiding. These tiles in addition to be

regions of non-interest, each has a very peaky spectrum, especially tiles 1 and 13 that can have a very high capacity that can use several peak-zero pairs. For instance use of 3 (peak-zero) pairs in tiles 1 and 13 and 2 (peak-zero) pairs in tiles 4 and 16, will accommodate 17,348 bits with an overall PSNR of 57.6 dB in the marked area. Note that use of one pairs of (peak-zero) for the whole image, can only accommodate 9,834 bits and not only the quality is dropped to 49 dB, but the regions of interest are also affected by watermark.

### *3.4 Use of spatial masking (high subjective quality)*

Another favourable property of image tiles is the ability to hide more data in the regions with high texture or edges, where the human visual system can tolerate more distortions. In this case, though highly textured areas do normally have a broad spectrum and hence a lower capacity for each (peak, zero) pairs, but one can use more (peak-zero) pairs, without subjectively impairing the marked image quality. For instance, in the Lena image of Fig 7, divided into 16 tiles and numbered from left to right and top to bottom, data are hidden in tiles 6 and 7 with 4 pairs, tile 10 with 5 pairs and in tiles 11 and 14, 3 and 4 pairs respectively. The overall capacity of these 5 tiles is 5528 bits, with an average quality in the marked area of 45.4 dB, as shown in Table 2, while the other 11 tiles have not been touched at all. The subjective quality of the image, in the marked and unmarked areas, can not be differentiated. Hiding the data in the whole image without tiling, requires 2 (peak, zero) pairs, for a capacity of 5409 bits and PSNR of 47.8 dB. Although this is a good quality, but close inspection shows some image artefacts in the plain areas. With 16 tiles, use of one pairs for all the tiles, can accommodate 6868 bits and a quality of 51.7 dB, much better than the whole image, but again the plain areas are affected that for some applications (e.g. medical) may not be acceptable.

### *3.5 Comparison*

Fig. 8 compares the performance of Ni et al.[11], Lin et al. [12] and Tsai et al. [13] against our proposed scheme (for 4 and 16 tiles) in terms of capacity and PSNR for the two extreme images of Im5 and Im10. For Im5, at low capacity of up to 10 kbits, our method with 16-tile image is the best, but for capacity larger than 20 kbits method [12] is better. For Im10, our 16-tile version outperforms all up to 20 kbits data hiding capacity and is inferior to [12] and [13] at 40 kbits. It should be noted that, here for fair comparison data is hidden uniformly all over the image. Had we used more peak-

zero pairs in some image tiles with narrower histograms, or, had we balanced the quality between the image tiles, where in each image tile capacity could be traded for quality, the performance of the image tiling method could be improved. Finally, our method with the ability of Region of Non-interest, can result in a better subjective picture quality, than all of these methods, which are applied to the whole image.

#### 4. Conclusion

We have shown that data-hiding based on the shifted histogram is better to be applied to image tiles than the whole image itself. This not only improves the data-hiding capacity, but also improves the marked image quality. This is mainly due to the fact that sum of the peaks of the individual pixel intensity histograms is greater than the single peak of the image histogram itself. Besides, the individual histograms are much narrower and sharper than the histogram of the image itself, creating more possibility for zeros, as well as making distances between the peaks and zeros in each image tile shorter. Finally individual histograms make it possible to distribute the embedding bits among the image tiles, such that while the regions-of-interest can be free from artefacts, data can also be hidden according to the perceptual characteristics of the human visual system.

## References

- 1 Delp, E.-J. : "Multimedia security: the 22nd century approach!". *Proc. workshop on Multimedia Systems* vol. 11, n<sup>o</sup>2, pp.95-97, 2005.
- 2 Acharya, R., Anand, D., Bhat, S. and Niranjana, U.C., "Compact storage of medical images with patient information," *IEEE Trans. Inf. Technol. Biomed.*, vol. 5, pp. 320-323, 2001.
- 3 Coatrieux, G., Sankur, B., and Maître, H.: "Strict Integrity Control of Biomedical Images". *Proc. Electronic Imaging, Security and Watermarking of Multimedia Contents*, SPIE, USA, pp.229-240, 2001.
- 4 Wakatani, A.: "Digital watermarking for ROI medical images by using compressed signature image". *Proc. 35th Hawaii International Conference on System Sciences*, pp.2043-2048, 2002.
- 5 Shih, F. Y., and Wu, Y.-Ta : "Robust watermarking and compression for medical images based on genetic algorithms". *Journal of Information Sciences, Elsevier*, vol. 175, n<sup>o</sup>3, pp.200-216 , 2005.
- 6 Jagadish, N., Bhat , P. S., Acharya, R., and Niranjana, U. C.: 'Simultaneous storage of medical images in the spatial and frequency domain', a comparative study. *Biomedical Engineering Online*, 3(1):record 17, 2004.
- 7 Macq, B., and Dewey F.: "Trusted Headers for Medical Images". *DFG VIII-DII Watermarking Workshop*, Erlangen, Germany, 1999.
- 8 Zhou, X. Q., Huang, H. K., and Lou, S. L.: "Authenticity and integrity of digital mammography images," *IEEE Trans. on Medical Imaging*, vol. 20, n<sup>o</sup>8, pp.784–791, 2001.
- 9 Li, M., Poovendran, R., and Narayanan, S.: "Protecting patient privacy against unauthorized release of medical images in a group communication environment" *Computerized Medical Imaging and Graphics*, vol. 29, n<sup>o</sup>5, pp. 367-383, 2005,
- 10 Coatrieux, G., Lecornu, L., Sankur, B., and Roux Ch.: 'A Review of Image Watermarking Applications in Healthcare'. *International Conference of the IEEE-EMBS*, pp. 4691-4694, 2006.
- 11 Ni, Z., Shi, Y. Q., Ansari, N., and Su, W.: 'Reversible data hiding'. *IEEE Trans. on Circuits and Systems for Video technology*, 16(3), pp. 354–362, 2006.
- 12 Lin C. C. , Tai W.L., Chang C.C., "Multilevel reversible data hiding based on histogram modification of difference images," *Pattern Recognition*, 41, pp. 3582-3591, 2008.
- 13 Tsai P. , ChenHu Y. , Yeh H.L., "Reversible image hiding scheme using predictive coding and histogram shifting", *Signal Processing*, 89 pp. 1129-1143, 2009.

## Figure and table captions:

### Figures:

Fig. 1 Intensity histogram of a human chest

Fig. 2 Cancer tissue Image (a) original (b) marked as a whole image (PSNR= 44.6 dB) (c) Histogram of the marked image

Fig. 3 Four-tiled Cancer tissue Image and their histograms (a) first tile (PSNR=48.00 dB) (b) second tile (PSNR=42.22 dB) (c) third tile (PSNR= 45.26 dB) (d) fourth tile (PSNR=49.06 dB)

Fig. 4 Ten original medical images

Fig. 5 PNSR versus capacity of the two extreme tiled-images

Fig. 6 (a) 1st (b) 4th (c) 13th (d) 16th tiles and (e) whole MRI image

Fig. 7 Selected tiles of Lena image with more texture

Fig. 8 Comparison between [11], [12], [13] and suggested scheme for (a) Im5 (b) im10

### Tables:

Table. 1 Maximum capacity and marked quality of whole, 4 and 16 tiles of 10 medical images of Fig 4.

Table. 2 Capacity versus PSNR

## **Acknowledgments**

This work is partially supported by the Spanish Ministry of Science and Innovation and the FEDER funds under the grants TSI2007-65406-C03-03 E-AEGIS and CONSOLIDER-INGENIO 2010 CSD2007-00004 ARES.



Figure 1

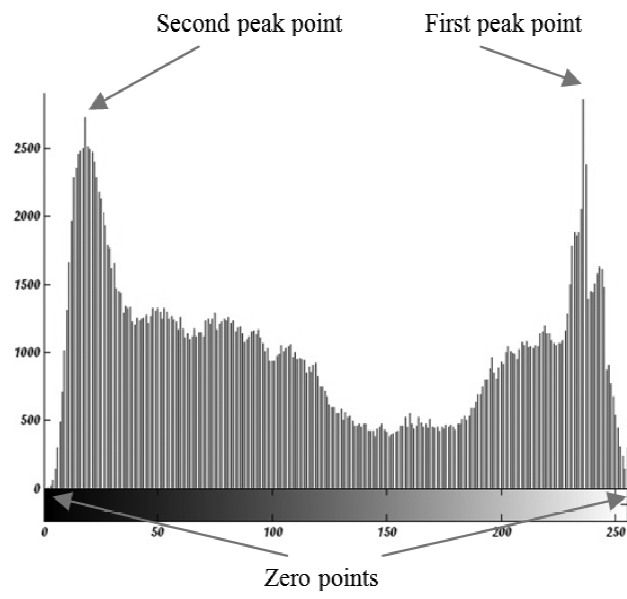


Figure 2

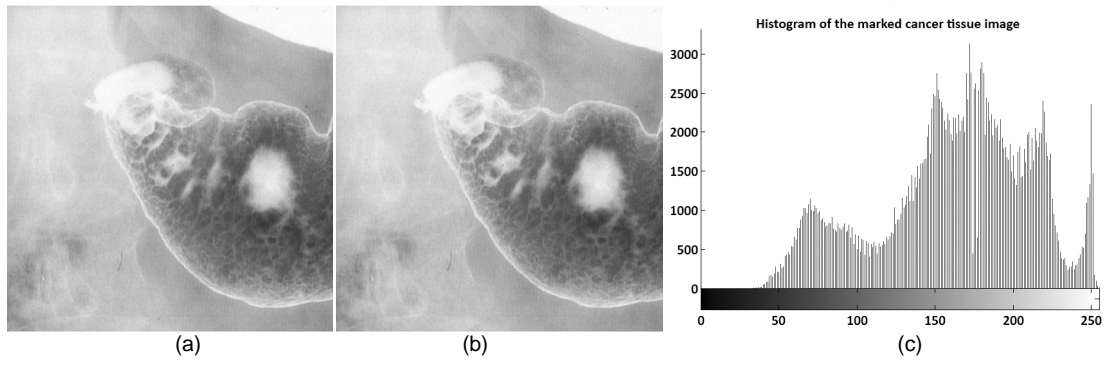


Figure 3

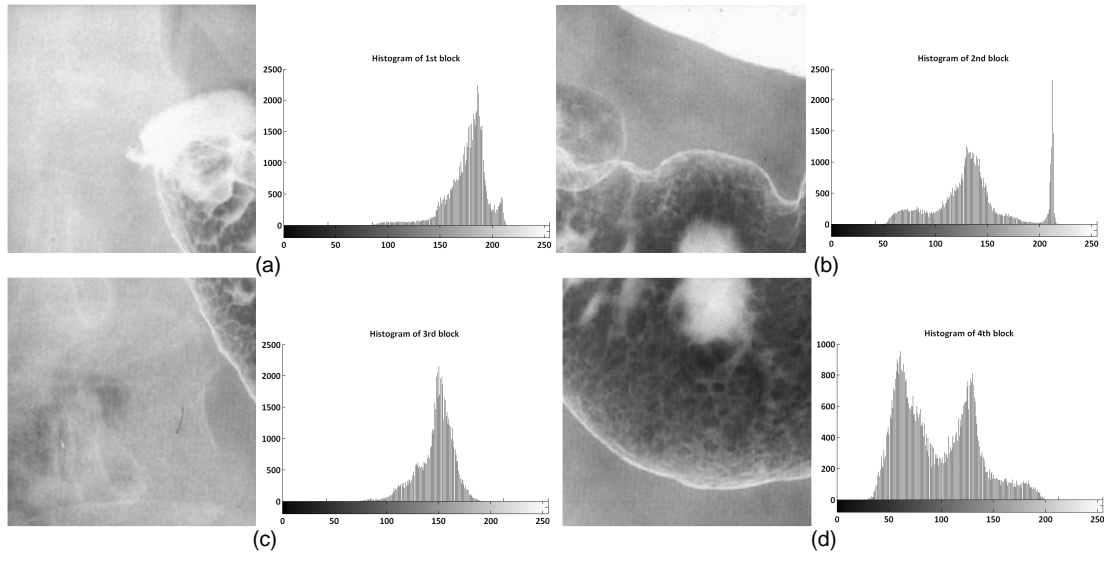


Figure 4

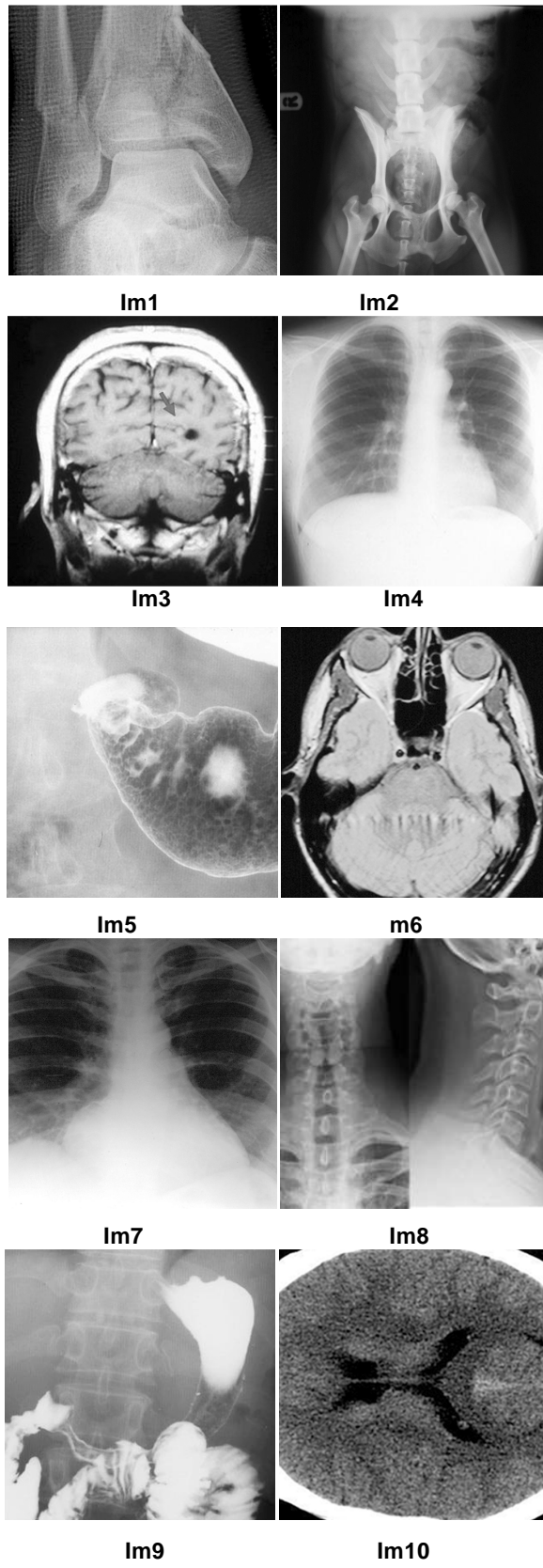


Figure 5

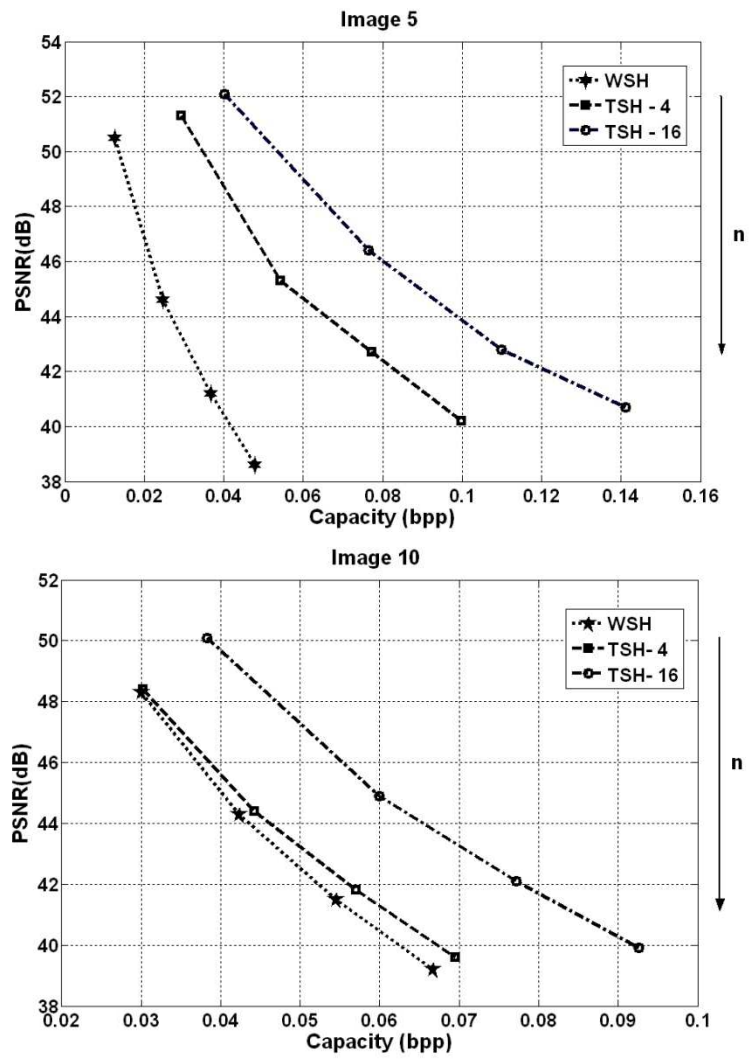


Figure 6

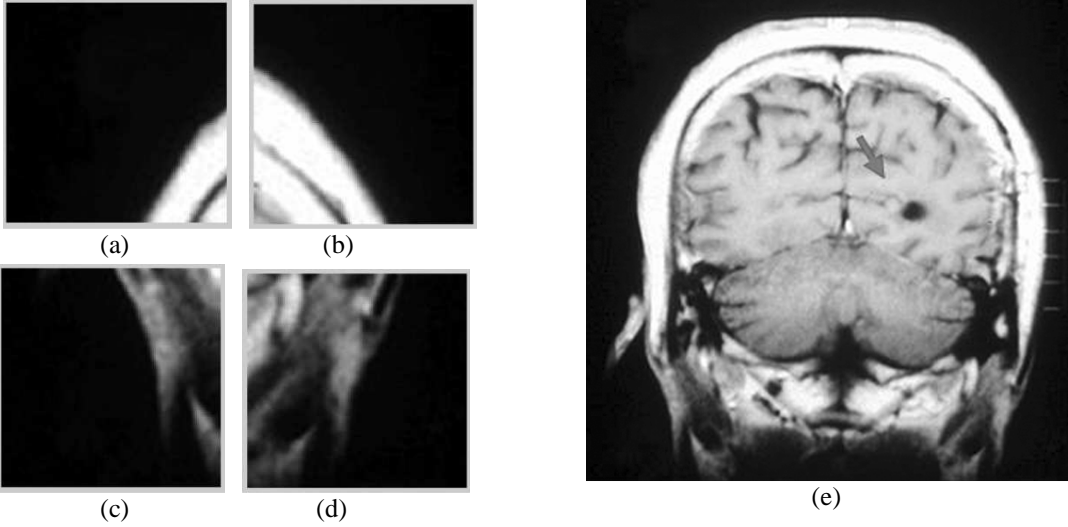


Figure 7



Table 1

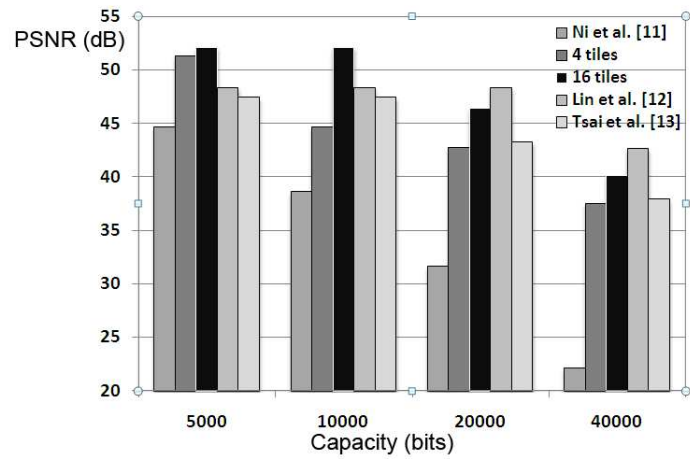
Image	Pure payload						PSNR of marked images (dB)		
	WSH		TSH-4		TSH-16		WSH	TSH-4	TSH-16
	n	bits	bits	Improvement %	bits	Improvement %			
Im 1	1	11480	12434	8	15679	37	<b>48.3</b>	<b>50.8</b>	<b>51.3</b>
	2	13955	15810	13	21495	54	<b>44.7</b>	<b>46.3</b>	<b>45.6</b>
	3	16076	19001	18	26847	67	<b>42.1</b>	<b>43.7</b>	<b>42.3</b>
	4	18091	22054	22	31934	77	39.0	<b>41.5</b>	<b>40.0</b>
Im 2	1	16811	18737	11	24549	46	<b>48.8</b>	<b>49.9</b>	<b>52.8</b>
	2	32638	35705	9	45713	40	<b>43.0</b>	<b>43.9</b>	<b>47.4</b>
	3	45296	50627	12	62402	38	39.7	<b>40.2</b>	<b>44.0</b>
	4	57110	62848	10	75324	32	37.1	37.5	<b>41.5</b>
Im 3	1	9834	10931	11	16668	69	<b>49.0</b>	<b>50.4</b>	<b>53.0</b>
	2	19515	20874	7	31385	61	<b>43.0</b>	<b>43.9</b>	<b>47.3</b>
	3	26720	29810	12	44201	65	39.4	<b>40.6</b>	<b>43.9</b>
	4	33918	37967	12	55528	64	37.0	38.1	<b>41.2</b>
Im 4	1	11144	15186	36	20577	85	<b>48.4</b>	<b>51.2</b>	<b>52.3</b>
	2	19774	27494	39	36266	83	<b>42.4</b>	<b>45.3</b>	<b>46.1</b>
	3	24591	34517	40	47586	94	38.8	<b>41.6</b>	<b>42.7</b>
	4	28534	40703	43	55604	95	36.4	39.1	<b>40.5</b>
Im 5	1	3276	7694	135	10552	222	<b>50.5</b>	<b>51.3</b>	<b>52.1</b>
	2	6492	14247	119	20070	209	<b>44.6</b>	<b>45.3</b>	<b>46.4</b>
	3	9629	20243	110	28841	200	<b>41.2</b>	<b>42.7</b>	<b>42.8</b>
	4	12528	26153	109	36988	195	38.6	<b>40.2</b>	<b>40.7</b>
Im 6	1	11181	11506	3	15208	36	<b>49.0</b>	<b>50.2</b>	<b>51.3</b>
	2	21833	22465	3	29425	35	<b>42.9</b>	<b>44.1</b>	<b>45.2</b>
	3	30184	31702	5	41715	38	39.3	<b>40.6</b>	<b>41.5</b>
	4	38181	40333	6	53286	40	36.9	38.0	39.0
Im 7	1	2729	4817	77	6560	140	<b>48.5</b>	<b>54.2</b>	<b>53.1</b>
	2	5413	9560	77	12916	139	<b>42.5</b>	<b>49.1</b>	<b>47.3</b>
	3	8096	14155	75	19107	136	38.9	<b>44.5</b>	<b>43.5</b>
	4	10652	18698	76	25010	135	38.0	<b>41.4</b>	<b>41</b>
Im 8	1	2121	4382	107	10711	405	<b>57.3</b>	<b>56.1</b>	<b>54.3</b>
	2	3978	8433	112	16776	322	<b>52.3</b>	<b>49.5</b>	<b>48.2</b>
	3	5825	12116	108	22612	288	<b>48.8</b>	<b>46</b>	<b>44.8</b>
	4	7664	15555	103	28050	266	<b>44.1</b>	<b>43.3</b>	<b>41.5</b>
Im 9	1	5081	9528	88	10955	116	<b>48.4</b>	<b>49.1</b>	<b>51.4</b>
	2	9931	16275	64	17028	71	<b>42.4</b>	<b>43.9</b>	<b>45.6</b>
	3	14218	22715	60	22908	61	38.8	<b>40.2</b>	<b>42.2</b>
	4	17422	28140	62	28350	63	37.4	38.2	39.8
Im 10	1	7861	7929	1	10045	28	<b>48.3</b>	<b>48.4</b>	<b>50.1</b>
	2	11083	11607	5	15724	42	<b>44.3</b>	<b>44.4</b>	<b>44.9</b>
	3	14280	14944	5	20242	42	<b>41.5</b>	<b>41.8</b>	<b>42.1</b>
	4	17473	18217	4	24262	39	39.2	39.6	39.9



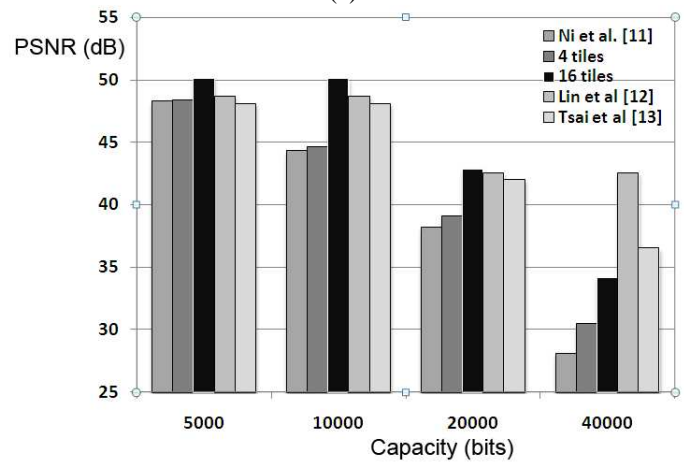
Table 2

Image	Capacity	PSNR	Number of pairs
6 <sup>th</sup> tile	801	38.9	4
7 <sup>th</sup> tile	1421	37.3	4
10 <sup>th</sup> tile	1418	41.0	5
11 <sup>th</sup> tile	640	46.5	3
14 <sup>th</sup> tile	1248	43.5	4
Whole image	5409	47.8	2
Whole with 16 tiles	6868	51.7	1
Whole with 5 selected tiles	5528	45.4	Different for tiles

Figure 8



(a)



(b)