HIGH CAPACITY, REVERSIBLE DATA HIDING IN MEDICAL IMAGES

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ABSTRACT

In this paper we introduce a highly efficient reversible data hiding technique. 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 in the whole image, our scheme can result in 30%-200% capacity improvement with still better image quality, depending on the medical image content.

Index Terms— data hiding, Image watermark, medical images

1. INTRODUCTION

Data hiding is the insertion of a message into a host document or cover media. 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. However, data hiding in medical images, due to their specific requirements impose certain constraints, which set some specific requirements. In fact high quality (fidelity), authentication, high capacity, frequent insertions and reversibility are the main requirements of medical files. 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) [1]. 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 [2], 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 square errors (NRMSE), indicating that the watermark is practically invisible [4]. On reversible data hiding, where the embedded content can be added or removed without affecting the original image quality, [5], 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 [6] or details are lost after lossy image compression [7]. For a survey on medical watermarking application, the readers may refer to [8].

Perhaps the histogram-shifted-based lossless data hiding algorithm proposed by Ni et. al [9] is one 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 the worse case $\text{PSNR}=10\times\log_{10}(255\times255/\text{MSE})=48.13\text{dB}$, which is regarded a very high quality and is suitable for medical images. In this paper we show how by applying shifted-histogram, not only the watermarked image quality can be improved, but more importantly, the data hiding payload can be significantly increased.

The rest of the paper is as follows. Characteristics of the proposed algorithm and its details are described in Section II. Experimental results are presented in Section III, and conclusions are drawn in Sections IV.

2. PROPOSED METHOD

The main idea in the shifted-histogram data hiding method is to find a pair of maximum and minimum in the image pixel intensity histogram and then shift the intensity of those pixels within the maximum and minimum 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 original histogram. Due to the created gap, the data hiding mechanism 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 coordinates 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 Interest: The image can be divided into parts such that, only the histograms of the non-region of interest image tiles are modified and the data is hidden.
2. High payload: In the shifted-histogram based data hiding method, the maximum number of hidden bits 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 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 pixels, 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 of 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.

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

2.1 Embedding
1. The image is first divided into N₀ non-overlapping image tiles (e.g. N₀ =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 distances between the chosen pairs), or according to any other criteria such as perceptual quality. The (Pᵢ, Zᵢ) pairs are then prioritized either based on objective or subjective quality, as explained above, with Pᵢ and Zᵢ as the intensity of the peak and zero.

3. The following iteration is executed n times for i =1: n.

4. For pair (Pᵢ, Zᵢ) the image tile is scanned and if:
   a) Pᵢ > Zᵢ, the gray values of the pixels between Zᵢ+1 and Pᵢ are reduced by one (shifting the range of the histogram [Zᵢ+1, Pᵢ] by 1 to the left). This creates a gap at gray level Pᵢ. The image tile is re-scanned and the gray values of the pixels with gray value of Pᵢ -1 are incremented by one if the bits of the to be embedded data are “1”, otherwise they will not be modified.
   b) Zᵢ > Pᵢ, the gray values of the pixels between Pᵢ +1 and Zᵢ -1 are increased by one. This creates a gap at gray value Pᵢ +1. Then image tile is re-scanned and the gray values of the pixels with gray value of Pᵢ 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 $n$, their positions will be treated as side information that needs to be transmitted to the receiving side for data retrieval.

2.2 Detection
For the given $N_b$, their embedding order and $n$, the following process is used 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 iteration is done $n$ 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. Otherwise, if it 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 it 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 $P_i$ 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 is no sufficient number of zeros the minima are used instead of zeros.

3. EXPERIMENTAL RESULTS AND EVALUATIONS
We have tested the performance of the proposed method for 4 and 16 image tiles, on a variety of medical images. The original image sizes were 512 ×512 pixels with 8 bit resolution. Table 1 summarizes the results of Cancer tissue original image sizes were 512 ×512 pixels with 8 bit for 4 and 16 image tiles, on a variety of medical images. The number of peak-zero pairs. Up to 4 pairs of peak-zero has been used but the number of peak-zero pairs can vary from one to another and they can be arranged such that for instance, the watermarked image quality is uniform across the whole image. The extra payload is dependent. For example, in Image number 6 (Im6), which shows the least average percentage of the watermarked image quality under tiling is always better than the whole image itself. On the other hand, in image 2 (Im2), albeit at a slightly lower quality, the degree of improvement in payload varies with marked image quality. The 4-tile and 16 tile images can hide on average more than 100% and 100-220% respectively over the whole improvement of 1-5 % for 4-tile and 30-40% improvement for the 16 tile images over the whole image.

Table 1 Maximum capacity and marked quality of whole and 4 tiles of Cancer tissue image (im2 of Fig 1).

<table>
<thead>
<tr>
<th>Image</th>
<th>Whole image</th>
<th>4 tiles image</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tile 1</td>
<td>Tile 2</td>
</tr>
<tr>
<td>Capacity</td>
<td>6492</td>
<td>4362</td>
</tr>
<tr>
<td>PSNR</td>
<td>44.6</td>
<td>42.22</td>
</tr>
</tbody>
</table>

Table 2 shows the maximum payload and the quality of 6 various medical images which are shown in Fig 1, under shifted histogram of whole (WSH), 4-tile(TSH-4 ) and 16-tile (TSH-16) versions. In each experiment the results were the average of 60 embedded sets of random bit stream messages. 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 has been used but the PSNR may not be acceptable at some higher 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 in all cases quality can be traded for capacity. For equal quality, the improvement in payload capacity can be better judged from Fig 2, for two extreme images of Im2 and Im6. For instance for a 42 dB image quality, in Im6 while 4-tile image has 5% larger capacity over the whole image, in 16-tile version, this extra capacity is about 42%. This extra capacity, for the most favorable image, Im2 of the above data base is 110% and 200% for the 4tile and 16-tile.
We have shown that data-hiding based on the shifted histogram is better to be applied to image tiles than the 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 tiles, such that while the region-of-interest data can be free from disturbance, they can also be hidden according to the perceptual characteristics of the human visual system and zeros in each image tile shorter. All in all improving the marked image quality, while maintaining high data embedding capability. Finally individual histograms make it possible to distribute the embedded bits among the image.

5. ACKNOWLEDGMENTS

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