A Benchmark for Medical Image Watermarking

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Abstract - The medical images with EPR embedded in it can be used for transmission, storage or telemedicine applications. There is a need of specific standards for the evaluation of watermarking techniques used for embedding EPR data on medical images. No existing benchmark addresses this issue. There are no universally accepted performance measures applicable for every watermarking system. In this paper a benchmark is proposed for the evaluation of medical image watermarking and data hiding techniques.

1. INTRODUCTION

Hiding patient data in the medical image is one of the applications of digital image watermarking. The patient data in the electronic format is called Electronic patient record (EPR).

All works reported in data hiding in medical image are watermarking for authentication and EPR hiding. The medical images of different modalities with EPR attached to them can be sent to the clinicians residing at any corner of the globe for the diagnosis. Embedding of EPR with medical images will save storage space of the Hospital Information System, enhance confidentiality of the patient data and save the bandwidth required for transmission. Obviously this will reduce the cost of diagnosis. This kind of a system requires a high level of security, which can be ensured by using digital watermarking techniques.

Literature is devoid of a systematic norms or regulations for watermarking medical images. Medical image watermarking communities around the world need a standard benchmark for the exchange of information globally. The currently popular benchmarks focus on evaluating imperceptibility and robustness under typical non-medical image degradation processes. They do not provide an evaluation scheme applicable for specific medical image types, or for typical degradations arising from medical image processing.

2. MEDICAL IMAGE WATERMARKING TECHNIQUES

Almost all the earlier works in medical image watermarking have focused mainly on two areas: 1. Tamper detection and authentication and 2. Embedding EPR in medical images. Tamper detection watermarks are used for identifying manipulations done on medical images. EPR data can be embedded into the medical image using spatial domain techniques as well as transform domain techniques. Spatial domain watermarking techniques are prone to degradations. The embedding technique must be lossless because of the stringent requirements on high quality in medical applications; however the number of embedded bits should be large enough for the clinicians to write their diagnosis report. Some of the available watermarking techniques used for embedding text information into medical images can be found in [2,3,4].

Popular Benchmarks: The important available benchmarks are Stirmark, Checkmark, Optimark and Certimark. All the these benchmarks share the common inefficiency of providing a platform for evaluating all kinds of image watermarking methods. This makes a room for research on devising a benchmark for all kinds of image watermarking.

3. A NOVEL BENCHMARK FOR MEDICAL IMAGE WATERMARKING

An ideal benchmarking procedure should involve examining the set of mutually dependent parameters of the watermarking system and it should clearly optimize the trade off between various constraints of watermarking. Various performance metrics are used to evaluate these parameters based on a specific application.

The requirements of watermarking such as imperceptibility, capacity and robustness are hampering each other. Therefore, a trade off is essential between these parameters. A proper evaluation has to ensure that all the selected requirements are met to a certain level of assurance. The evaluation method for medical image watermarking techniques differs from the other benchmarks because of the following constraints.

3.1 Cover Image Set

The benchmark incorporates a number of cover images of varying size. The medical images are available in different modalities such as CT, MRI, US, and X-ray. The Hospital Information System contains Integrated Medical Image Database and Retrieval System that enables doctors to browse patient images at any time. Such a system allows medical images in different modalities to be integrated into an image database server with the DICOM standard. Digital watermarking can imperceptibly embed messages without changing image size or format. So the watermarked medical image can conform to the DICOM format.

3.2 Capacity

Though the capacity of watermark is expressed in bits per pixel, more convenient unit that can be generally applied to EPR text data hiding in Medical images is Maximum Number of Embedded Characters (MNEC). For medical image watermarking, the capacity must be as high as possible. This is to remove a constraint of available space for hiding annotations, authentication message, first information report and detailed diagnosis report.

3.3 Imperceptibility Measures

The quality assessment of an image after watermarking is done to measure the amount of distortion due to the watermarking. Peak Signal-to-Noise Ratio (PSNR) and Mean Squared Error (MSE) are the most widely used objective image quality/distortion metrics, but they are not correlating well with perceived quality measurement. However, certain portions of the cover image can effectively mask the presence of the watermark. The error signals that are visible to human eye need to be taken as noise for visual quality assessment. The important masking effects of HVS are explained in the following section.

1) Visual Masking: When an image component is in the frequency and orientation, that image component becomes less conspicuous to the human eye. The important masking effects are Luminance Masking, Contrast masking and Texture masking. Human eye is less sensitive to changes in textured areas than in smooth areas. The texture masking effect is determined by local frequency distribution and texture direction. The texture masking effect is described using a parameter called Noise Visibility Function (NVF).

2. Structural Similarity Measure: Another perceptual metric used to model the degradation of watermarked medical images is the Structural Similarity Measure (SSIM). Image quality assessment based on SSIM is based on the fact that the HVS is highly adapted to extract structural information from the viewing field. SSIM metric is ideal for testing of similarities in medical images because it focuses on local rather than global image similarity.

3 .Watson Metric: Regions of non-regular and highly changing luminance in the cover image are able to mask the presence of watermark. This phenomenon is given by Watson model. The basic aim of the model is to weight the DCT coefficients in an image block by its corresponding sensitivity threshold. The threshold is a compound function of luminance masking and contrast masking. Watson metric is used to calculate the perceptual error in the watermarked image in Just Noticeable Difference (JND) units.

3.4 Region of Interest (ROI)

An important factor to be considered while watermarking medical images is that medical images contain Region of Interest (ROI). In medical images, ROI is an area that contains diagnostically important information and must be processed without any distortion. The ROI is usually selected in the spatial domain. In spatial domain watermarking techniques, the pixels in non-ROI parts can be modified directly.

1. Capacity-NVF-ROI Measure: The watermark capacity is considered as the number of bits that can be embedded into the particular cover image with low error visibility. Therefore the capacity measure must be associated with the content of image. The capacity of the cover image is evaluated as,

$$C = W \log_2(1+(\sigma_\omega^2)/ (\sigma_n^2)) \qquad (1)$$

Where σ_ω^2 is the variance of MWI and σ_n^2 is the noise variance and W depends upon the number of pixels. For an image of size N × N, W = N × N/2.

3.5 Attacks

The benchmark evaluates the performance of the system under typical processing operations during storage and transmission of medical images. Various types of noises usually degrade medical images during transmission and the overall noise can be modeled as Gaussian. The noise due to long-term storage of the image is modeled as speckle noise.

3.6 Robustness Measure

The robustness of the watermark to various medical image-processing operations can be evaluated using the Bit Error Rate (BER) between the embedded message and the extracted message. The BER is evaluated by varying the strength of each degradation process.

4. RESULTS AND DISCUSSION

In order to identify the regions of noise visibility in the cover images, NVF values were calculated at each pixel. First local variance was measured using a 3×3 neighborhood in order to calculate NVF values. 128×128 size, 8-bit gray scale MRI image of heart was used as the cover image. The NVF image obtained corresponds to the cover image is shown in *Fig. 1*. It was found that NVF values were close to 0 in edges and textured portions, whereas it was close to 1 in flat portions of the image.

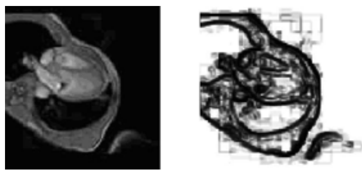

Fig.(1) Cover image and its NVF map

In the LSB technique, the least significant bit of each pixel in the cover image is modified using the watermark. The total number of bits available in the LSB plane was 16384 bits. This much amount of bits is sufficient to meet the capacity requirements of EPR data hiding in medical images. The analysis of LSB plane of the cover image reveals that the LSB plane contains a large amount of redundancy. Each character in the EPR data is encoded using 7-bits and watermarked into the redundant bits of LSB plane.

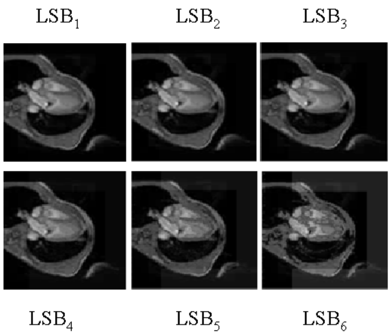

Fig.(2) Distortion due to watermarking in LSB planes

The capacity can be further improved by inserting the watermark into the higher order bit planes. *Fig. 2* illustrates the distortion occurred in the cover image when 3456 bits of the watermark were inserted into six planes and it could be seen that, fourth plane onwards the distortion became visible. Variation in the different imperceptibility measures is tabulated in *Table 1*.

LSB Plane	SSIM	PSNR dB	Watson metric
1	0.98	49.4	0.028
2	0.92	43.3	0.056
3	0.84	37.4	0.110
4	0.75	31.4	0.210
5	0.65	25.6	0.394
6	0.56	19.8	0.726

Table 1. Variation in imperceptibility measures

4.1 Visual quality Vs Capacity

The Visual quality Vs capacity graph is used to estimate the maximum number of characters (MNEC) that can be embedded into the cover image within the imperceptibility limits. Using LSB method, encoded text information was embedded into cover images of different modalities. The WPSNR values were calculated for various amounts of embedded characters. The results obtained for images of different modalities were averaged. The WPSNR value that ensures imperceptibility of watermark was found to be 40 dB. It was observed that LSB techniques ensure minimum degradation to cover image.

For evaluating WPSNR, error (difference between cover image and watermarked image) was scaled by the corresponding NVF values evaluated at each pixel. It was found that CT images provide the highest value of imperceptibility for the given number of embedded characters compared to images in other modalities. This is due to the high contrast between adjacent regions in CT images.

Capacity of the ROI mapped to horizontal details was calculated. Finally, the capacity of horizontal details without ROI was calculated as per *(1)*. In the blind watermarking scenario, two different pseudorandom sequences were embedded in the ROI and non-ROI regions so that the watermark detector can correctly identify the ROI. As expected, the number of bits that could be embedded into the horizontal details decreased with the increase in the size of ROI.

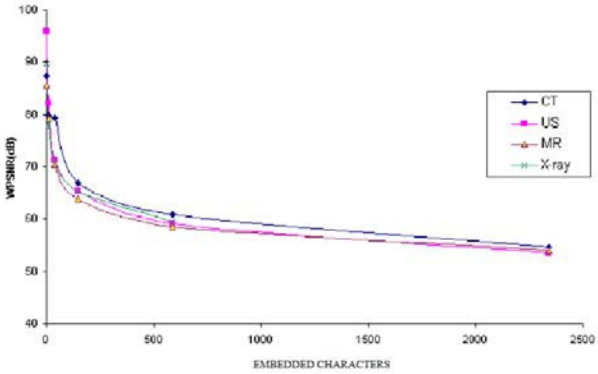

Fig.(2) Degradation in visual quality with capacity

4.2 Visual quality Vs Attack strength

The degradation in the visual quality of the watermark is illustrated using Visual quality Vs Attack strength graph. WPSNR decreased with increase in the variance of Gaussian noise.

The WPSNR used to measure visual degradation of medical images with noise uses Contrast Sensitivity Function (CSF) as the weighting factor. The frequency response of CSF is modeled as a band pass filter and the error signal is filtered by this BPF.

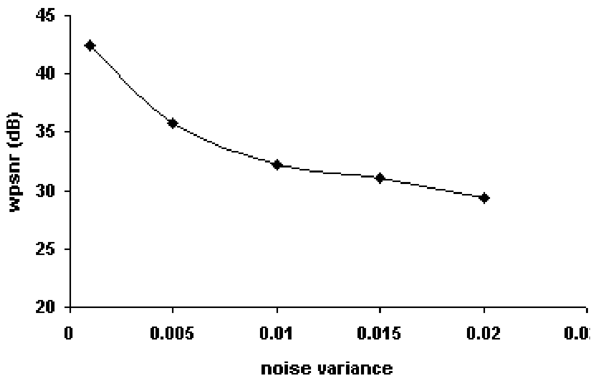

Fig.(2) Degradation in visual quality with attack

4.3 Bit error rate Vs Attack strength

Bit error rate Vs Attack strength graph is used to find out the robustness of the watermark against various attacks. The bit error rate between the original and extracted watermark increased with the increase in the variance of speckle noise.

It was observed that the watermarking capacity in wavelet domain is much lower compared to that of spatial domain but the robustness is better than that of spatial domain. This is because the watermark embedded using spatial domain techniques is more sensitive to pixel manipulations whereas, it remains unchanged when embedded into wavelet subbands.

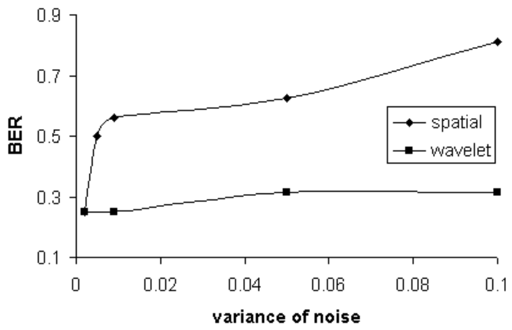

Fig.(2) Degradation in visual quality with attack

5. CONCLUSION

A benchmark was proposed for text data hiding in medical images. Bounds of capacity, imperceptibility and robustness were discussed. These benchmark standards will be of immense use for the global ROI image data hiding community for the design and evaluation of the algorithms. Authors are involved in making a complete benchmark datasheet for the researchers in this field.

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