Embedded Importance Watermarking for Image Verification in Radiology

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ABSTRACT

Digital medical images used in radiology are quite different to everyday continuous tone images. Radiology images require that all detailed diagnostic information can be extracted, which traditionally constrains digital medical images to be of large size and stored without loss of information. In order to transmit diagnostic images over a narrowband wireless communication link for remote diagnosis, lossy compression schemes must be used. This involves discarding detailed information and compressing the data, making it more susceptible to error. The loss of image detail and incidental degradation occurring during transmission have potential legal accountability issues, especially in the case of the null diagnosis of a tumor. The work proposed here investigates techniques for verifying the voracity of medical images – in particular, detailing the use of embedded watermarking as an objective means to ensure that important parts of the medical image can be verified. We propose a result to show how embedded watermarking can be used to differentiate contextual from detailed information. The type of images that will be used include spiral hairline fractures and small tumors, which contain the essential diagnostic high spatial frequency information.

Keywords: Watermarking, fractures, diagnosis, tumor

1. PROBLEM STATEMENT

It is essential to have verification of medical image integrity prior to any diagnosis. More specifically, sufficient detail must be present. Two classic examples include non-displaced hairline fractures Fig. 1 and small tumors Fig. 2.

These images are good examples, as the diagnostic information is highly detailed and can often be missed on initial radiographs. The relevant aspects of medical diagnostic images that influence their usefulness include scale and size of the medical image. Detail is critical in order to highlight specific location and density information. In the past, digital medical images have been of large size and stored without the loss of any information. The long term digital storage or mobile transmission of such images is prohibitive without the use of image compression to reduce the image file sizes. As a typical example a mammogram may be digitized at 2048×2048 pixels at 16bpp, leading to a file which is over 15 megabytes in size.[1]

The use of lossless formats is widely accepted because no image information is discarded and data is interchangeable from one format to another. One such example is the conversion of a Digital Imaging and Communication in Medicine (DICOM) format to the more widely used lossless Joint Photographic Experts Group JPEG[2] standard. This simply leads to a different representation of the image file, but guarantees consistent visual appearance and diagnostic quality of the image.

For the purposes of remote diagnosis, lossy compression must be used to discard some of the image data as a result of the mobile bandwidth constraint. This typically involves the use of the widely accepted JPEG[3] standards.

The type of information discarded by JPEG is high spatial frequency information which is frequently necessary for correct diagnosis, especially for images where detail is important. Unfortunately lossy schemes are

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Figure 1. Toddler's Fracture: This typically occurs in young infants as a spiral hairline tibial shaft fracture. This is often invisible on initial radiographs.

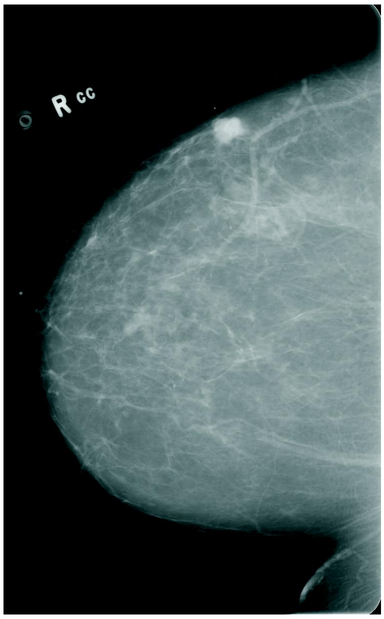

Figure 2. Encased papillary carcinoma of a breast. This mammogram shows a dense lobulated high density nodule located at the 12 o'clock position on the right breast.

Figure 3: Close up of toddler's fracture.

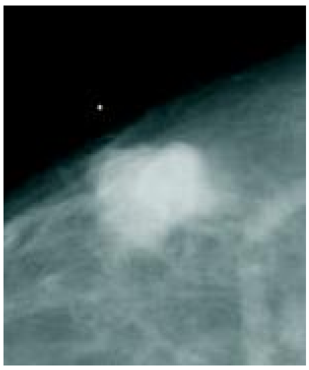

Figure 4: Close up of encased breast carcinoma.

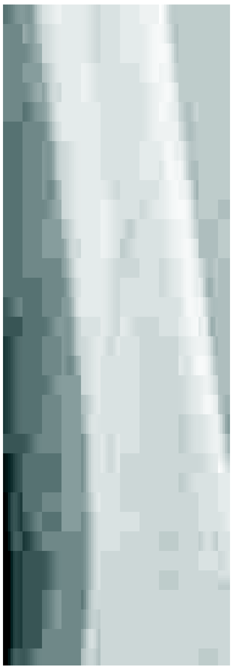

Figure 5. Close up of toddler's fracture with the use of lossy JPEG compression. Immediate loss of diagnostic information is apparent as the spiral hairline fracture is masked and displaced by block boundaries. The lower part of the fracture also appears to have vanished.

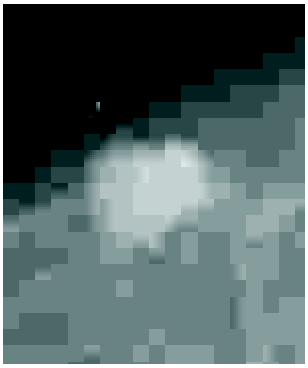

Figure 6. Close up of encased breast carcinoma. In this situation there is a clear loss of location information as the edges of the encased carcinoma are shifted to the block boundaries of the JPEG compressed image.

viewed with suspicion by many members of the scientific and medical community, who believe that image alteration may lead to loss of diagnostic or scientific value. Despite delivering impeccable quality most of the time, lossy compression can introduce false information or artifacts such as ringing and blurring which become apparent at low bit rates. As extreme examples, see Figures 5 and 6. These types of standards are also designed to conceal errors when they occur, such as lost blocks of data over a mobile link. This would be obvious if the data was lost from the JPEG file header, however the incidental degradation would be less obvious and in need of careful attention. Further possible threats to medical image integrity include destruction and modification of the contents of files and records.[4]

2. THE NEED FOR QUALITY ASSESSMENT

Human observers can easily assess the quality of a distorted continuous-tone photographic image without examining the original as a reference. However objective image quality assessment is feasible only when knowledge of the types of image distortion are available.[5] Most previous works on image quality assessment[6 7 8] assume a knowledge of a reference image, the most popular parameter being the peak signal-to-noise ratio (PSNR). These goals have been aimed at evaluating the visual difference between a target image and a reference. The requirement of having a reference image for comparison limited the application of this type of performance measure. Works presented in[9] and[10] involved investigating metrics that could be used to assess image quality by attempting to determine the extent of JPEG compression artifacts using arbitrary algorithms. Such quality metrics failed when trying to quantify the incidental degradation over mobile links. Current practical measures of ensuring medical image integrity during mobile transmission involve the use of digital signatures, whereby encrypted versions of the patient records are inserted in the gray levels of medical image pixels. Although the damage to the diagnostic medical imagery is minimal, such schemes are not sufficiently robust in mobile communication.[4, 11]

In order to meet the mobile constraint and the need to provide assurance for image quality and integrity, we have combined two technologies together. These include semi-fragile watermarking to be used as an objective means to validate the image quality at the receiving end and the use of Region-of-Interest (ROI) compression to meet the bandwidth constraint. We have extended this work and introduced the new concept of importance watermarking.

2.1. Region of Interest Compression for Mobile Medical Image Communication

Research pertaining to ROI compression of medical imagery shows that diagnostically important regions must be preserved at high quality, while the rest of the image is only important in a contextual sense and assists the viewer to observe the position of the ROI within the original image.[1, 12, 13] The most recent work[14] involved combining lossy compression with the ROI capabilities of JPEG2000. It was shown through extensive subjective testing that the diagnostic value of the medical image did not degrade for very low bit rate coding. Such approach leads to better diagnostic value, since the ROI is exactly the area where all diagnostic information is located and where the majority of the 'bit budget' is stored. To illustrate this point, a spiral hairline fracture has a ROI losslessly compressed and the peripheral regions coarsely quantized using the baseline JPEG[3] quantization table and quantized relatively coarsely as a means to give the reader a visual stimulus Fig 7. On inspecting the

Figure 7: ROI compressed hairline fracture

resulting quantized 8×8 discrete cosine transform (DCT) coefficient blocks surrounding the ROI, the original set of 64 coefficients has been reduced to an average of 2. Consequently the majority of the bit-budget is devoted to the region of interest, making the compression scheme useful in for low bandwidth mobile communication. This does assume that the ROI chosen is relatively small in comparison to the rest of the image.

2.2. Importance Semi-Fragile Watermarking as an Integrity Check

If the authentication information is lumped and localized within some representation of the image it is possible to detect the modifications as well as verify the diagnostic integrity. This technique can be performed in either the spatial or DCT transform domain of a medical image. Within this work semi-fragile watermarking has been used. This technique has been designed to withstand application specific transformation operations, such as lossy compression, but is designed to be corrupted as a result of malicious manipulations or incidental degradation over a mobile link.[15] Consequently we can use this to provide an integrity check for the critically important regions such as the ROI. In this way peripheral image regions surrounding the ROI can be lossy compressed and robustly watermarked to survive this compression. Furthermore, the surrounding watermark is based on important properties of the region of interest rather than being based on a random sequence. Consequently after transmission and before diagnosis, verification can be acknowledged that the most important parts of the image have arrived intact.

3. EXPERIMENTAL PROCEDURE

3.1. Background

The first stage in this work was to find a means to differentiate between what is important and what is not important in medical images. The key feature that must be conserved in these types of images, discussed in Section 1 is detail. All detail is essential, however more importance can be placed on large detail and less on finer detail. This led to the development of a meaningful and realistic weighting function that was used to place varying amounts of importance on different levels of detail. The relevance of this experiment was to objectively evaluate how detail was lost as the level of JPEG compression with the desired goal of ultimately converting a set of microblock coefficients to a 4-bit string that could be embedded in the peripheral regions using semi-fragile watermarking. A known constraint on this system would be that at least the same area of peripheral image would have to be transmitted with the ROI.

3.2. Setting Up Detailed Information

A convenient and universal means to evaluate detail can be done through the use of a chart containing alphabetic letters of varying size. This approach is nearly identical to the optometry chart used to evaluate the quality of a person's vision, as the end result is an objective conclusion. In order to objectify from such a chart, more importance has been placed on large letters than on small letters, although all letters are important. This is highly relevant to medical imagery, where large detail is more important than fine detail. Characters of height 5 pixels to 15 pixels going up in a pixel height of 2 have been chosen very specifically, as characters of smaller size could not be represented and consequently in its digital format no longer represented detail as it was not possible to determine the letter. Characters of larger size no longer represented detail, but spatially spread information, that would quite unlikely be lost with. Because the sizes of these characters varied in a linear way, the importance given to each of the characters was also linear, hence we chose to give characters of height 15 an importance weighting of 6 and those 5 pixels high an importance of 1.

3.3. Performing Stepwise Compression With Subjective Evaluation

Compression on this character set was performed in a manner similar to JPEG and took place on an 8×8 microblock level. Using this methodology, all of the DCT transform coefficients were slowly removed my following the JPEG zigzag sequence illustrated in figure 8. The importance was placed on specifically removing the coefficients so that we could subjectively evaluate which DCT coefficients represented important detailed information, which should be reinforced using semi-fragile watermarking and which ones did not pertain to detailed information. This point is illustrated in Figure 9, which shows the original randomly generated letter set. Figure 10 demonstrated the effect of removing the first three coefficients of each microblock. What this clearly demonstrates is that these three coefficients play little role in the preservation of detailed information, as all of the letters are still present. As we are trying to objectively evaluate the loss of detailed information

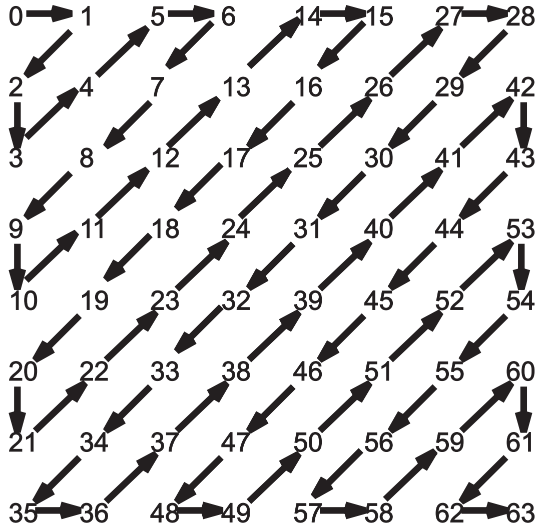

Figure 8: JPEG Zigzag Scan

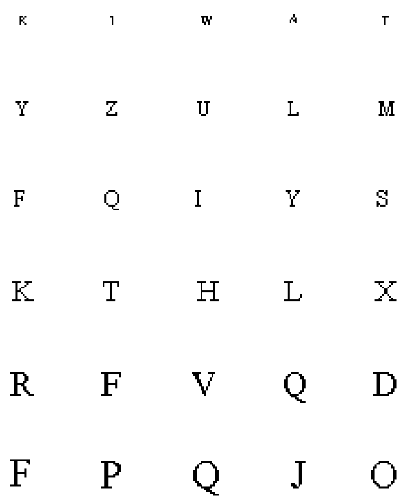

Figure 9:

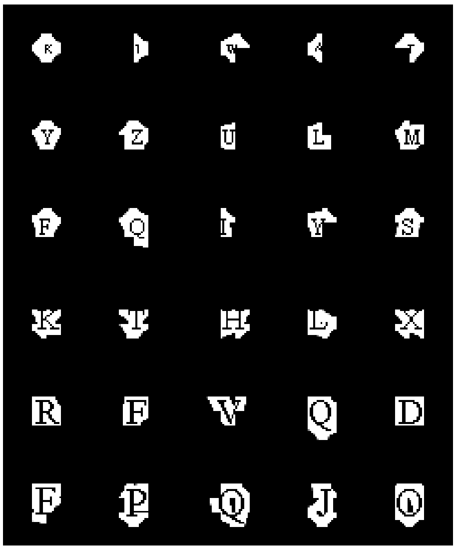

Figure 10:

due to compression and incidental degradation, these coefficients would serve little purpose as an important representation of the ROI. An objective evaluation technique was developed so that it was possible to determine which coefficients were most important. Using the letter weighings from Section 3.2, after varying levels of compression took place, the letters which could be read correctly were used for the objective score and weighed accordingly. Since the overall maximum obtainable result was 95, the results were normalized from 1 to 100. This graph tells us that the most important coefficients involved in representing detailed information are the 35th to 45th coefficients of the JPEG zigzag scan. Consequently it would be most useful to use these coefficients as the data to be embedded around the ROI so that medical image verification can be made.

3.4. Useful Applications of this Research

Watermarking can provide the ultimate guarantee of embedded authentication that no other protection may ensure. This would be expected to have useful spin-offs for law enforcement and military image analysts who may inspect imagery under special viewing conditions when typical assumptions regarding distortion visibility

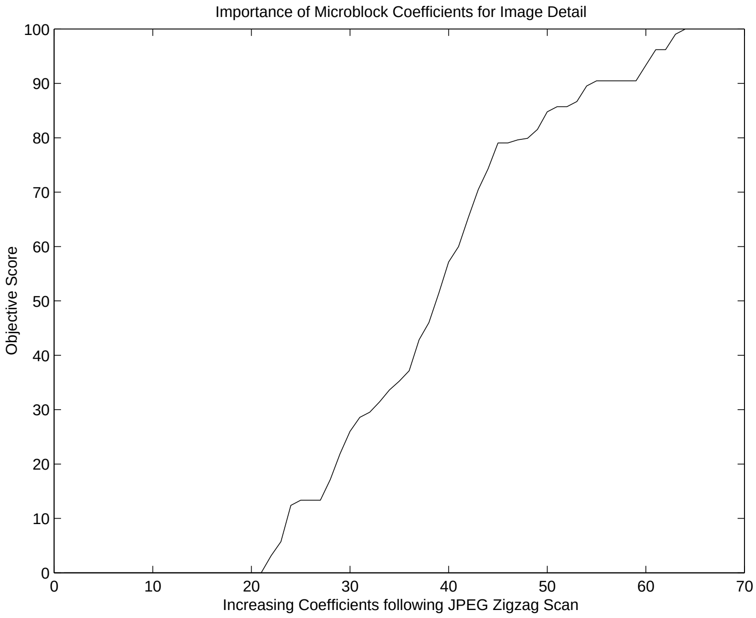

Figure 11: Representing the Importance of Microblock Coefficients

do not apply. Such conditions could include extreme zoom, iterative filtering as well as enhancement.[16]

Furthermore, implementing watermarking as a means to objectively evaluating the quality of a medical image without a reference can be extended to possible implementations in other types of multimedia, such as monitoring image or video quality for quality control systems or benchmarking image/video processing systems and algorithms. This could also be used to optimize algorithms and parameter settings in image/video processing systems and for intelligent memory management in digital cameras. Due to constrained storage space, a digital camera must choose a quality factor that does not sacrifice the visual quality but maximises the compression ratio.[9] A limitation is that authentication based on watermarking cannot replace the classical cryptographic authentication protocols that protect communication channels. This type of authentication protects the communication link by ensuring that no one can impersonate the sender and that the image data has not been tampered with. This is most commonly achieved by attaching a hash of the image encrypted with the private key of the sender and encrypting the result with the public key of the recipient.[17]

4. CONCLUSIONS

This work brings together the technologies of semi-fragile watermarking and the recently emerged ROI coding. Importance watermarking is discussed here as a convenient means to establish the integrity of medical images by verifying that a significant amount of detail is present in the image. This allows the receiving physician to be able to trust the image and to be able to make a diagnosis without the concern that the image had degraded to the point of mis-diagnosis.

5. ACKNOWLEDGEMENTS

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