Multiple Medical Image ROI Authentication Using Watermarking

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ABSTRACT

Medical images are now almost all gathered and stored in a digital representation for easy transmission and archiving. High resolution is mandatory for a detailed diagnosis, which requires accurately known location and density information regarding the important features of the image called the regions of interest (ROI). Such features may include non-displaced fractures or small tumors that can often be difficult to identify. A reduction in size by using compression is necessary for efficient transmission over a wireless link where remote diagnosis may be an only option in many cases. Despite rapid advances in lossy compression, most research in the compression of medical imagery specifies that the ROI must be conserved as much as possible or compressed with a lossless or near-lossless algorithm. To ensure diagnostic integrity of these crucial regions after transmission, a multiple watermarking technique has been developed which can be used to verify the integrity of the ROI prior to diagnosis. This has the benefit of assuring that incidental degradation has not affected any of the crucial regions. A strong focus is placed on the robustness of the watermarking technique to JPEG compression as well as the issue image file size and quality tradeoff. The most useful contribution in our work is assurance of ROI image content integrity after image files are subject to incidental degradation in these environments. This is made possible with extraction of DCT signature coefficients from the ROI and embedding multiply in the Region of Backgrounds (ROB).

Keywords: Authentication, Robust Watermarking, Region of Interest

1. INTRODUCTION

Digital storage and transmission of diagnostic medical images has been proven to have an advantage over their analog counterparts. This has been especially favorable for ease of acquisition, storage and retrieval. The communication of digital imagery has become more prevalent, resulting from decreasing cost of transmission bandwidth, more efficient use of available spectrum and improved display capabilities of mobile phones and hand-held Personal Digital Assistants (PDA's). In order for these types of images to be stored with maximum quality, lossless compression schemes must be used. The most challenging issue is transmitting these images when limited bandwidth is available. Lossy compression schemes address this issue by substantially reducing the image file size, which results in images that can be transmitted more quickly. There remains a need of authentication for medical images and provision for compression so that feasible transmission is possible. The use of a simple system that also provides some compatibility with current image compression standards is essential as complex compression schemes are expensive to develop and deploy.[1] A technique is presented that can be used to verify the integrity of images with a critically important ROI prior to any informed judgements or decisions that are made after transmission. Semi-fragile watermarking that is robust to JPEG[2] compression is embedded around the ROI into the Region of Backgrounds (ROB) to provide authentication of these types of images. This provides assurance that important detail is present and has not been lost. Such degradation may be a result of incidental degradation or compression levels exceeding a specified level. The type of image that will be used to highlight this type of detail includes a spiral hairline fracture, which is a classic example of this type of critically important region-based detailed information. This can be extended to any image with a critically important region. Transmission of a small image file is possible without sacrificing image quality in the ROI where no watermark is placed. This scheme is designed with flexibility in mind and can be applied in one of two ways illustrated in Fig. 1. The first operates externally to the JPEG standard and allows for the entire image to be compressed to specified level. This results in good bit rate performance consistent with typical levels of

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JPEG compression at the extent of some degradation of the ROI. The other scheme operates by embedding a watermark is an identical way, but encoding the DCT coefficients directly into a hybrid-coded JPEG-like file. This technique results in minimal degradation and near-lossless encoding of the ROI at the expense of a larger file size and slightly inferior bit-rate performance. This must function within the framework of the JPEG standard rather than operating as an external system.

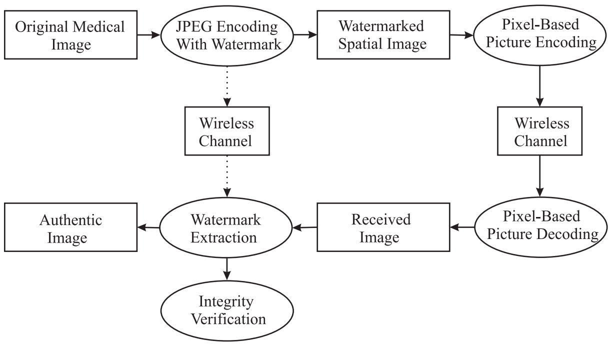

Figure 1. Two possible wireless image scenarios. The first transmission involves dual encoding of the ROI and ROB resulting in a larger file size and improved ROI quality, while the second transmission involves the complete lossy JPEG encoding of the entire image or any near-lossless pixel encoding methodology, such as GIF or JPEG-2000.

2. PROBLEM STATEMENT

2.1. The Problem of Authentication

Adding small amounts of noise to corrupt the bitstream of an image file that has been channel-coded does not usually affect the importance of the diagnostic features present in the image after transmission has taken place. Incidental distortions that are not corrected through channel decoding[3] may slightly distort the file structure of the compressed image file without any noticeable change to perceptual quality. This could involve a loss of diagnostic feature information. Hence it is critical to authenticate image quality prior to any diagnosis that is made.[4] A classic example of this type of feature information is shown in an infant's fracture of Fig. 2. This type

Figure 2. Non-displaced hairline fracture from the leg of an infant, which is often invisible on initial radiographs. If this type of image was transmitted from a hospital to a mobile hand-held device there would be an immediate need to evaluate image quality as a result of the possible loss of image transform coefficients in the ROI or unexpected levels of compression that might degrade feature content in this region.

of loss which may go unnoticed resulting from incidental degradation as a result of transmission is highlighted in Figure 3.

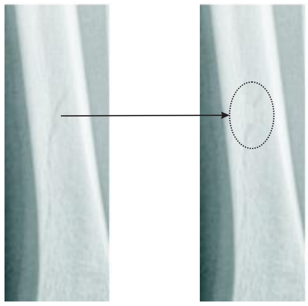

Figure 3. The loss of diagnostic information has occurred in the image on the right, where two microblocks have lost all representative DCT coefficients except for the average or DC coefficient. This type of incidental degradation could occur with the loss of data during transmission and in most cases would easily be noticed. This is an unusual situation, where the loss of detail is hard to distinguish.

2.2. The Problem of Lossless Storage

To maintain as much detail as possible, images with critically important content including medical images used in radiology are commonly stored without loss of information using lossless compression schemes, which provide for complete image restoration. The long term digital storage or mobile transmission of such images is prohibitive without the use of lossy image compression to reduce the image file sizes. As a typical example, a mammogram may be digitized at 2048×2048 pixels at 16 Bits Per Pixel (bpp), leading to a file which is over 15 megabytes in size.[5] The use of lossless formats is widely accepted because no image information is discarded and data is interchangeable from one format to another. This simply leads to a different representation of the image file, but guarantees consistent visual appearance and diagnostic quality of the image. For widespread usage, lossy compression involves the use of JPEG standards. The most common of these which is implemented in most hardware is the well established Baseline JPEG. This involves performing the Discrete Cosine Transform (DCT)[6] on 8×8 image pixels to create micro-blocks, quantization of these coefficients and entropy coding of the result. Contrary to excellent developments in lossy image compression, these types of schemes are 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.

3. PREVIOUS WORK IN ROI WATERMARKING

The concept of ROI watermarking was first proposed by[7] who placed signature information into the ROB. A progressively compressed version of a signature image is used and the most significant information is embedded into the region closest to the ROI. This method allows for the signature image to be detected with moderate quality from a clipped version of the image that included the ROI. This system was intended for use over web-based medical image database systems with primary focus placed on ensuring copyright and intellectual property protection. The ROI area in the original image is specified prior to compressing the signature image using a progressive encoding algorithm to generate a bitstream. This allows for increasing visual detail with as the extracted bitstream is followed. The payload is embedded into pixels around the ROI in a spiral way as depicted in Fig. 4. Another recent ROI watermarking scheme is proposed by Lie *et al*,[8] which is designed to operate within the framework of the JPEG-2000 standard, targeting ROI compressed images. A dual watermarking scheme is proposed in which critical image content is to be authenticated. Two different types of watermarks are used, one being naturally fragile and the other robust. The embedding process for the robust watermark takes place at differing resolution layers to ensure that malicious changes are detected and provides flexibility in determining the extent of alteration to discriminate intended attacks from unintended ones. In order to accurately detect which areas have been altered, the first watermark $W1$, which is sensitive and fragile is hidden in the ROI. The second watermark, $W2$ is composed of features of mid-frequency wavelet sub-bands and is robustly watermarked into the ROB using features from the ROI as the signature shown in Fig. 5. The robust watermark proposed is designed to survive after acceptable levels of low-pass filtering and JPEG-2000 compression and not to survive malicious attacks. This signature is based on wavelet coefficient properties of the ROI, where

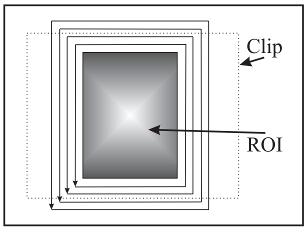

Figure 4. Since the ROI is the most critical aspect of a medical image, it may be clipped to include the ROI. The signature image is compressed using Embedded Zerotree Wavelet (EZW) coding so that the whole image can be reproduced with average quality and the entire signature image can be retrieved. The quality of the resulting signature image is directly correlated to the length of the bitstream extracted.

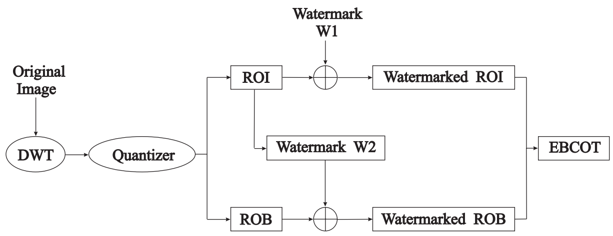

Figure 5. Block diagram of proposed dual watermarking scheme using ROI features as part a watermark to be robustly embedded in the ROB. This is designed to withstand typical levels of JPEG-2000 compression. To be consistent with this standard, scalable image coding is used.

features are extracted based on absolute differences between corresponding coefficients in the $LH3$ and $HH3$ subbands on 8×8 blocks. Similarly in this work a signature is based on on the absolute differences between corresponding coefficients in adjacent DCT tiles from inside the ROI, which have been uncorrelated as part of the signature extraction process.[8] mentions that his procedure degrades the ROB significantly, however this is not a primary concern as the ROB area is typically encoded at a low quality and gains minimal attention from users. The main focus of the works by Lie *et al*[8] and Wakatani *et al*[7] is copyright protection and assurance that malicious attacks on the embedded watermarks are prevented. Our focus is primarily concerned with integrity verification as images are to be transmitted in error-prone lossy transmission channels, such as those encountered in mobile phone telephony to those in Wireless Local Area Networks (LANs.) The most useful contribution in our work is assurance of ROI image content integrity after image files are subject to incidental degradation in these environments. This is made possible with extraction of DCT signature coefficients from the ROI and embedding multiply in the ROB.

4. AUTHENTICATION WATERMARKING TECHNIQUE USED

If the signature information is lumped and localized within the ROB it is possible to authenticate and verify the diagnostic integrity of such images. A simple method to multiply watermark involves embedding in the same shape of the ROI in the eight regions surrounding the ROI or fewer regions if the space in the ROB is unavailable. A visual impression of this method is shown in Fig. 6. Multiple embedding can give the receiver additional confidence in the unlikely event that both a watermark and signature are corrupted in an identical way and the watermark is falsely detected as authentic. It may also be of benefit if one watermark is corrupted. Semi-fragile (also termed robust) watermarking is specifically designed to withstand application specific transformation operations, such as lossy compression and geometric distortions,[9] but is designed to be corrupted as a result of undesirable alterations such as malicious manipulations and incidental degradation over a mobile link which may or may not be perceptible to the receiver. Semi-fragile robust signature embedding ensures that the watermark survives JPEG compression or slight degradation up to a point where the value of the work is lost. Because ROI compression has been successfully subjectively evaluated in ROB of diagnostic medical images,[10] the radiologist can have greater confidence that the diagnostic value of the image has not been degraded.

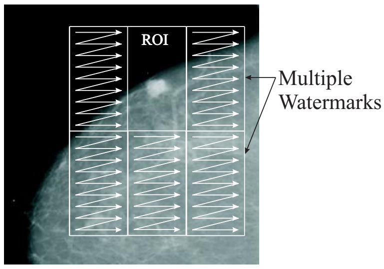

Figure 6. Multiple embedding in the ROB: The algorithm embeds a signature into multiple regions surrounding the ROI or in fewer regions if space is unavailable. For the case of the tumor above, five regions are used as there is limited space above the ROI Watermarking takes place following the direction of the arrows.

4.1. Basis of Signature Extraction

The basis of singular semi-fragile watermark extraction and embedding was initially developed by,[9] which is designed to survive a specified level of JPEG compression. Standard lossy image compression systems involve converting an image into some transform domain, such as wavelet or block DCT domain and quantizing the coefficients in order to reduce their entropy. Coefficients are quantized to a level proportional to how easy it is to perceive changes in them and the property of quantization of coefficients is exploited to remove redundancy in the image. Let $x \bullet q$ be the result of quantizing x to an integral multiple of a quantization step size, q:

$$x \bullet q = q \left[\frac{x}{q} + 0.5 \right]. \tag{1}$$

Consider s to be a real valued scalar quantity and q_1 and q_2 as quantization step sizes with $q_2 \leq q_1$, then

$$((s \bullet q_1) \bullet q_2) \bullet q_1 = s \bullet q_1. \tag{2}$$

If s is quantized to an even multiple of the larger step q_1 and then by a smaller step q_2, the effect of the second quantization can be reversed. The watermark should survive as long as the quantization that is performed during compression uses smaller step sizes. The watermark embedding and extraction procedure is designed to survive typical levels of JPEG compression, where images are quantized in the block DCT domain. The quantization step size for each coefficient depends on its frequency. These step sizes are obtained by multiplying the transform coefficients by a predefined quantization table, which is scaled by a constant. A signature is extracted from the low frequency terms of the micro-blocks of the ROI and embedded into the high frequency terms of the ROB as a semi-fragile watermark, which is illustrated on a block level in Fig. 7. This is important as the low-frequency terms represent the most important picture information that cannot be degraded through incidental degradation. High frequency coefficients can be used for the embedding in the peripheral regions, as these areas are diagnostically less important and will be degraded through compression. A signature for the

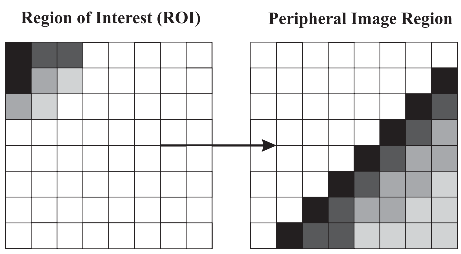

Figure 7. Spatial representation of the bits used for the signature (left) from the ROI and the bits used for the watermark (right) corresponding to the peripheral regions. Matching shades indicate where the payload bits go.

image is extracted by converting the medical image into its 8×8 block DCT representation and grouping blocks of the image into pseudo-random pairs according to a specified seed. For each pair of DCT blocks, 8 corresponding

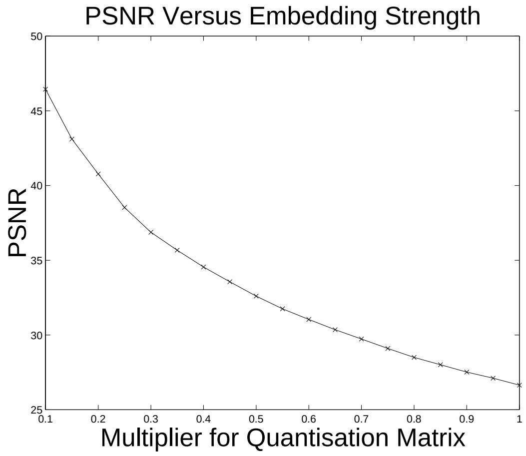

Figure 8. Deterioration of image quality with increasing embedding strength with resulting distortion quantified with the Peak Signal to Noise Ratio (PSNR). This is to be expected and is unavoidable as robust watermarking is used, which is nearly always perceptible to the observer. Increasing the embedding strength allows for the watermark to survive greater levels of compression at the expense of a more perceptible watermark.

low frequency coefficients are compared to obtain 8 bits of the binary signature. Consider two blocks that have been grouped C_a and C_b, then:

$$\text{signature bit} = \begin{cases} 0 & : \quad C_a[i,j] < C_b[i,j] \\ 1 & : \quad C_a[i,j] \geq C_b[i,j], \end{cases}$$

where i and j are the coordinates of a low frequency coefficient from Fig. 7. So that the reader can have some perspective on the extent of image degradation resulting from varying embedding strengths of watermarking. A hundred randomly selected grayscale images were tested for their Peak Signal to Noise Ratio (PSNR) after using embedding took place, as seen in Fig. 8. The greater the embedding strength, the more compression the image can survive and the more perceptible the watermark will be. This is not a problem as removal of the watermark can be performed easily at the receiving end.

5. SYSTEM IMPLEMENTATION OF DUAL ENCODING SCHEME

The main sub-systems used in the systematic design of the ROI semi-fragile watermarking scheme designed to work within the framework of JPEG are illustrated in Fig. 9. The image undergoes a block-based DCT specified by a tile or block size, which is typically 8×8 pixels. These coefficients are rounded and quantized and entropy[11] encoded. Those areas not shaded in grey include operations within the framework of the standard that can be used for more accurate ROI integrity verification than the system that operates externally to JPEG. The ROI in its transform representation replaces the same region in the full image whose coefficients have been quantized. This ensures that the ROI is stored near-losslessly while the ROB is compressed using lossy JPEG compression and contains at least one watermark.

6. PERFORMANCE THROUGH ROBUSTNESS TESTING

Survival of JPEG compression is one of the primary requirements of the ROI watermarking scheme. This is mandatory if operation external to JPEG is required, where the pixel-based image compression method is treated as part of the communication channel as shown in the flow diagram of Fig. 1, ignoring the wireless channel on the left side of this diagram. The watermarked image is permitted to undergo types of lossless compression, which will not degrade the image pixels or lossy JPEG, which can be applied up to a threshold specified by the user by the embedding strength. Robustness to varying levels of JPEG compression took place on 100 grayscale images of arbitrary types and varying resolutions from 256×256 to 1280×1280 pixels. The ROI was specified to occupy

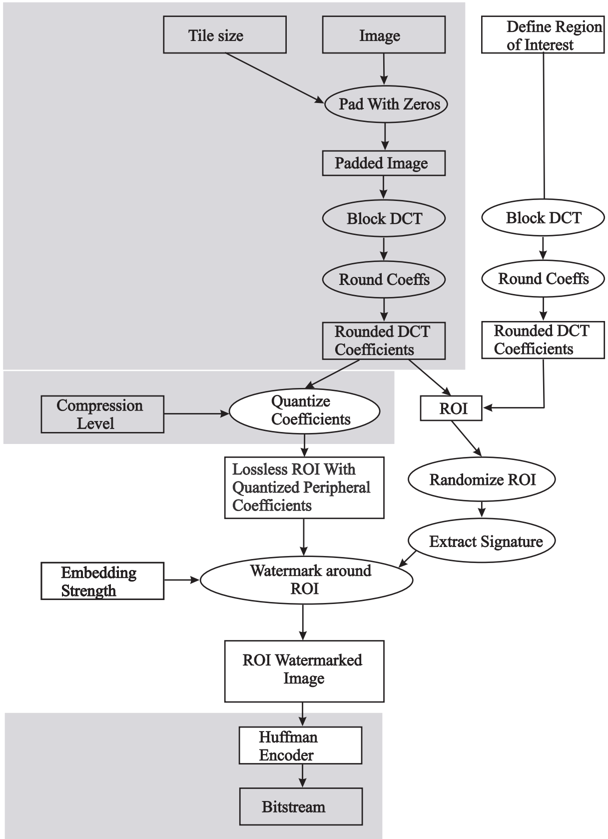

Figure 9. Dual encoding scheme designed to work within the framework of the JPEG standard. A ROI is specified and copied from an image that then undergoes a block-based DCT and quantization to minimize the number of non-zero coefficients for the purposes of high compression resulting in improved bit-rate performance. The compression level is specified by the user as a quantization table multiplier. Sub-systems standard to JPEG are shaded in grey.

a sufficiently small area at the center of each image so that 8 watermarks could be embedded around this region. Results are shown in Fig. 10. The results of this test shown in Fig. 11 demonstrate that the ROI watermarking scheme survives JPEG compression levels up to and exceeding the watermark embedding strength used on 90% of the images. This is shown to be consistent for three typical JPEG compression levels. These results are almost identical to those obtained by[12] where the performance of a similar watermarking method was tested where a signature was extracted from an image and a singular watermark embedded in the same region. As the scheme developed involves embedding a signature into the same coefficients in 8×8 DCT transform blocks, it is expected to survive similar levels of compression resulting in correlating sets of results. Approximately 10% of the images do not survive JPEG compression for quantisation levels exceeding the embedding strength. This problem can easily be rectified by setting the embedding strength slightly above the level of required JPEG compression.

7. BIT-RATE PERFORMANCE OF HYBRID CODING SCHEME

If the image is sufficiently robustly watermarked and converted to spatial domain for complete JPEG compression, the resulting file size is directly related to the level of compression. This results in a bit-rate performance that is identical to JPEG. If degradation of the ROI through JPEG quantization is not permissable and hybrid coding is preferred as illustrated in the flow diagram of Fig. 9 the bulk of the 'bit budget' will be stored in the ROI. This is because quantisation does not take place in this region and all ROI transform coefficients must be encoded, which are typically non-zero. As the ROB can undergo compression through quantisation, the majority of coefficients will be zero. This will result in a file size that is dependent on the size of the selected ROI. The larger this region

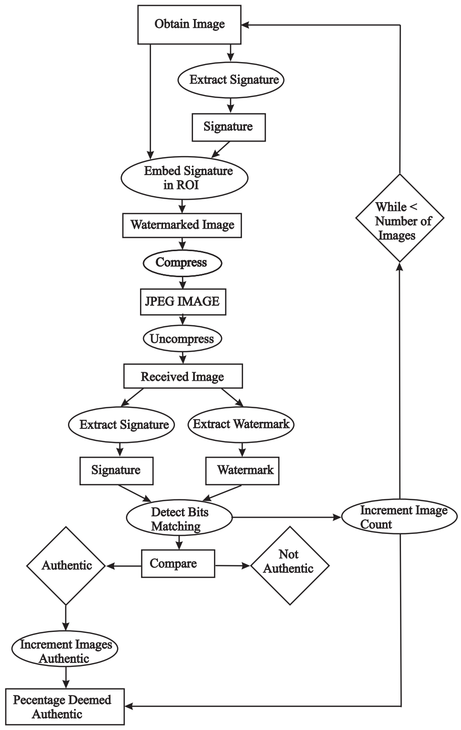

Figure 10. System to test the robustness of ROI watermarking system. The signature extracted from the ROI is embedded within the surrounding block-based DCT domain of the image. This is subjected to gradually increasing levels of JPEG compression and converted back to a spatial representation. The signature and the watermarks are extracted and compared to authenticate the image. To accommodate minimal bit errors resulting from conversion from transform to spatial representation a 5 percent error is permissable on comparison of extracted signature with extracted watermark for a match.

is, the more near-lossless compression is required, the larger the file size. For a typical fracture or tumor, the area of the ROI does not typically extend beyond 20% of the entire image. This is also verified in work by Foos *et al*[13] and Anastassopoulos *et al*[10] where ROI Maxshift JPEG-2000 compression was utilized to compress these types of medical images. Strom[5] also validated the effectiveness of combined lossy and lossless JPEG compression with these types of ROI sizes. It was shown through extensive subjective testing that the diagnostic value of the medical image did not degrade for very low bit rate coding. These approaches reinforce that the ROI is exactly the area where all diagnostic information is located. Bit-rate performance was evaluated in Fig. 12 with and without the use of watermarking and with sizes of ROI varying from complete lossy compression, where the peripheral regions were the entire image to the extreme of having the entire image encoded near-losslessly as a ROI. The most practically applicable areas of these curves includes those areas up to and around having a 20 percent area devoted to the ROI. Within this area of the curve the use of one or more embedding regions does not significantly affect the size of the medical image file. It would appear that each embedding region in Fig. 6 increases the file size by approximately 0.1 bpp, which without watermarking results in a compression level of 2 bpp. The increase in file size is insignificant in comparison with complete near-lossless JPEG encoding that provides minimal compression of 5 bpp of the original grayscale image. After baseline JPEG compression, which corresponds to using a quantization multiplier of 1, it is typical for the resulting quantized 8×8 DCT coefficient ROB blocks to be reduced from 64 to an average of 2 coefficients. This confirms the majority of the bit-budget is devoted to the ROI, which makes the compression scheme useful for low bandwidth mobile communication. This does assume that the ROI chosen is relatively small in comparison to the rest of the image.

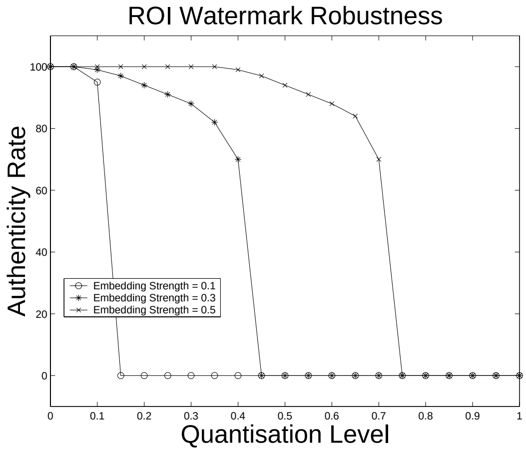

Figure 11. Testing the robustness of 100 images with the semi-fragile ROI watermarking scheme designed to withstand JPEG compression. As expected, the system fails the authentication test consistently after each of the three watermark embedding levels.

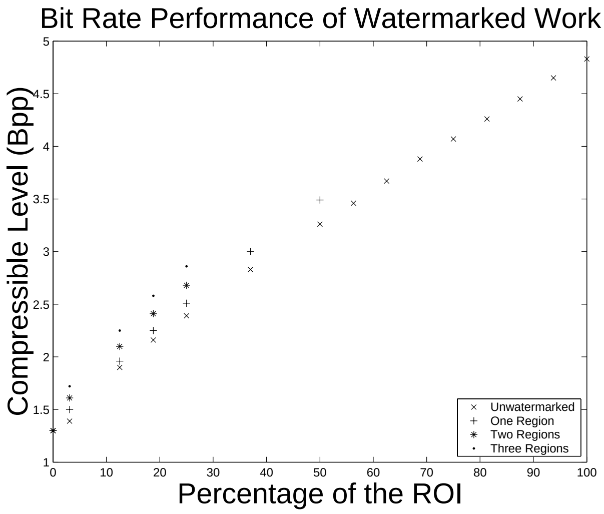

Figure 12. Bit-rate performance which can be compared with entire lossy JPEG compression, where the area of the ROI is zero to entire lossless compression in which the percentage of the ROI is 100.

8. KNOWN LIMITATIONS

Robust watermarking around a known ROI assumes that there is no uncertainty in defining and separating the critical region from the peripheral region. This introduces the possibility of human error in making a decision, which is likely to be more probable if the decision must be made quickly for an immediate transmission. Implementing a ROI watermarking scheme used in conjunction with hybridly coding the ROI and ROB does not ensure perfect lossless encoding of the ROI. As the scheme involves using sub-systems of the JPEG standard, rounding errors are expected when the ROI is converted to a DCT representation and back to a spatial equivalent. The authentication watermarking technique used is only designed to be robust to specified levels of baseline JPEG compression. It does not survive geometric distortions, as this results in a completely different set of DCT coefficients. Consequently features such as automatic resizing which can be present in some PDA's would need to be addressed. Poor survival of other lossy compression methodologies, such as GIF and JPEG2000 is expected as the watermarking methodology is tailored to baseline JPEG.

9. CONCLUSIONS AND FUTURE DIRECTIONS

The use of watermarking can be used to verify the integrity of digital images. A method is developed which is designed to be used on images that have critically important regions. The scheme is designed to perform multiple watermarking around the ROI containing feature information from this region. This technique can provide assurance that this region has not been corrupted as a result of incidental degradation resulting from a wireless link or that the ROI has not exceeded a compression level threshold. As watermarked images can be compressed, a smaller file size is achievable. Using this technique verification of ROI integrity as well as wireless communication is achievable and allows the user to evaluate quality of this region in a received image without the need of a reference. This is most useful for transmitted medical images where high levels of quality assurance are mandatory prior to making any diagnosis. The methodology can be applied in one of two ways, the first which fits in a modular way into the JPEG standard resulting in minimal changes and hybrid coding of the ROI and the ROB with the benefit of superior ROI quality. The second and more general approach operates extraneously to the standard providing greater compliance and improved bit-rate performance. This results in a degraded ROI when lossy JPEG is used on the watermarked image pixels or improved picture quality if lossless picture encoding techniques are used. Although the scheme has been designed for compliance with existing hardware and standards in mind, the principle of watermark extraction and embedding could be extended for application in JPEG2000 by using randomly selected and appropriately chosen wavelet coefficient pairs and embedding in a similar fashion in the wavelet transform domain. Embedded robust watermarking for ROI integrity verification can allow for compression and provision of image integrity and could be extended for usage in any image with a critically important region.

10. ACKNOWLEDGEMENTS

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