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Enhancing Robustness and Imperceptibility with a Texture-Based Adaptive QIM Approach

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Abstract

This paper proposes a new approach for image data hiding that aims to improve both robustness and imperceptibility. The proposed approach is based on a texture-adaptive quantization index modulation (QIM) method that takes into account the local characteristics of the image texture to optimize the embedding process. The approach is evaluated using various image datasets and compared to existing state-of-the-art techniques. The results show that the proposed approach achieves better performance in terms of robustness against various image processing attacks, with BERs of zero in some attacks, while maintaining a high level of imperceptibility with PSNRs exceeding 46 decibels. It can be deduced that adaptation and normalization of the embedding strength arguments can enhance the QIM methods' performance. The proposed approach has potential applications in image authentication, copyright protection, and data hiding.

Keywords: Image data hiding, Imperceptibility, Quantization index modulation, Robustness, Texture analysis.

اتعزيز المتانة وعدم الإدراك من خلال نهج تعديل مؤشر التكميم المتكيف القائم على النسيج

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الخلاصة

تقترح هذه الورقة نهجًا جديدًا لإخفاء بيانات الصور يهدف إلى تحسين كل من المتانة وعدم الإدراك. يعتمد النهج المقترح على طريقة تعديل مؤشر التكميم التكيفي للنسيج (**QIM**) ، والتي تأخذ في الاعتبار الخصائص المحلية لنسيج الصورة لتحسين عملية التضمين. يتم تقييم النهج باستعمال مجموعات بيانات الصور المختلفة ومقارنتها بأحدث التقنيات الحالية. أظهرت النتائج أن النهج المقترح يحقق أداءً أفضل من حيث المتانة ضد هجمات معالجة الصور المختلفة ، مع الحفاظ على مستوى عالٍ من عدم الإدراك. النهج المقترح له تطبيقات محتملة في مصادقة الصور ، وحماية حقوق النشر ، وإخفاء البيانات.

1. Introduction

A limitation of the standard QIM method is its use of a fixed step size and embedding strength, which does not fit well with the nature of images that are considered inconstant time domain signals and causes imperceptibility degradation in some images. Another such limitation is its drawback in dealing with volumetric scaling applied to the signal, which in

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turn affects the ability to retrieve the right watermark (robustness dropping). So some watermarking schemes tend to adjust their step size and embedding strength adaptively in a perceptual way according to the Human Visual System (HVS) as a response to the first type of limitation to get high fidelity. Trying to find some normalization ways to deal with the signal's fixed gain is a remedy for the second limitation type [1].

Dealing with watermarking schemes resembles, in some manner, the early communication schemes, where there are two noise sources. The difference here (with watermarking systems) is that one of these noise signals is well known at the transmitter side (encoder) as what is called "side information." Actually, what is intended here is the host (cover) signal [2].

According to Costa's work [3], it is proven that two channels undergo two noise sources, such that the first channel knows one of the noise sources at the transmitter side (but with the absence of such knowledge at the receiver side) and has the same capacity as the second channel, which completely doesn't have such knowledge at both sides. So, this idea, which says that one noise source won't mess up the signal being sent, can be used in the field of watermarked transmissions, where the cover (host) signal is used as a noise source to hide the important watermark information signal. Chen and Wornell came up with the QIM [4], which is a method for watermarking that uses Costa's idea by using a structured lattice code for embedding and decoding, which prevents interference with the cover signal. According to the basic QIM, intervals (quantization step size and embedding strength) in between these structure codes are fixed. Thus, this basic approach is vulnerable to low fidelity because it handles all embedding areas in the same way and with the same importance. The other main problem with QIM is that it is sensitive to volumetric scaling. This means that any change in the signal amplitude (the brightness of the image) can affect the efforts to extract the embedded watermark. Research [5] addresses this problem to some extent. So, it's important to find a way for the quantization step size to scale linearly in response to this kind of volumetric scaling so that the decoder can use the scaled version of the step sizes that depend on embedding.

2. Related Work

As the main aim of watermarking is copyright protection [6], [7], many methods in this regard have given the watermark's robustness more consideration compared to the imperceptibility factor. Thus, in this respect, the pioneering host signal interference rejection (QIM) method has been widely relied on in many studies due to its elegant properties in providing relatively undeniably reliable extracted watermark information. In spite of these good properties, the QIM unfairly treats the embedding areas, ignoring the perception demands by utilizing a fixed quantization step size for embedding data in each embedding area, leading to some watermarked image fidelity degradation. Thus, many studies have addressed this matter in their concerns to give the imperceptibility factor more interest and trade off with the robustness factor by finding a way to adapt this quantization step size by adopting the perceptual models for the area in consideration. For instance, in [1], the authors adopted what is called the Watson perceptual model to modify the QIM watermarking scheme to have an adaptive quantization step size based on the slacks that are computed utilizing the Discrete Cosine Transform (DCT) domain. such that it is possible to determine modification limits for any DCT coefficient before a noticeable distortion appears to the naked eye. And as the basic QIM scheme is sensitive to the amplitude scaling attack, they implemented the Rational Dither Modulation (RDM) scheme to overcome this problem. [8] and [9] also present partial solutions to this problem.

In the same way, the [10] paper used the Watson perceptual model to make a scheme with an adaptive quantization step size that is resistant to some noise attacks and some common image processing operations. In [11], the Just Noticeable Difference (JND) was used to find the right adaptive step size based on the idea that the perceptual model has a JND threshold before a change in the embedding area is noticeable. Hence, each area can be modified during the embedding process in relation to this threshold. [12] made a JND model based on three functions: sensitivity, luminance, and contrast. This was done to make the quantization step size fit the structure features that are so related to the perceptual model. Another strategy for getting the tradeoff between robustness and imperceptibility can be seen through the studies that act to exploit the DM schemes to reduce the embedding artifacts of fidelity degradation due to this scheme's characteristics in imposing a form of independence between the embedding's noise and the cover signal, as well as in preventing the accumulation of the quantization error and hence mitigation of the quantization error artifacts. For instance, [13] followed such a strategy with the aim of getting such a trade-off. The belief in conducting post-processing operations to get some quantization distortion compensation (DC) has gained a great deal of support in some other studies. Following this approach, [14], for instance, exploited this distortion compensation to get a more efficient approach toward achieving the watermarking objectives.

3. Problem statement

The problem that the paper "Enhancing Robustness and Imperceptibility with a Texture-Based Adaptive QIM Approach" tries to solve is the need for a better way to hide image data that can improve both its robustness and its invisibility. Conventional data hiding techniques often suffer from low robustness, meaning that the hidden data can be easily detected or destroyed by various image processing attacks, such as compression, filtering, or cropping. On the other hand, high imperceptibility is also required, meaning that the embedded data should not significantly affect the visual quality of the image. The paper proposes a new approach based on a texture-adaptive QIM method that takes into account the local characteristics of the image texture to optimize the embedding process. The aim of this work is to enhance the robustness and imperceptibility of image data hiding and to demonstrate the effectiveness of the proposed approach through experimental evaluation and comparison with existing state-of-the-art techniques.

4. Methodology

The methodology for "Enhancing Robustness and Imperceptibility with a Texture-Based Adaptive QIM Approach" involves the following steps:

1. Dataset preparation: The authors select several image datasets for experimental evaluation, including standard benchmark datasets such as Lena, Baboon, and Barbara.
2. Texture analysis: The authors apply a texture analysis method to the image datasets to extract the local characteristics of the image texture, which are used to guide the embedding process in the proposed approach.
3. Texture-adaptive QIM embedding: The authors propose a new texture-adaptive QIM method for data embedding. The method takes into account the local texture characteristics of the image to determine the optimal quantization step size and secret message embedding rate.
4. Robustness evaluation: The authors evaluate the robustness of the proposed approach against various image processing attacks, such as compression, filtering, noise addition, and cropping. Robustness is measured by the bit error rate (BER) between the original and extracted messages [15].

5. Imperceptibility evaluation: The authors evaluate the imperceptibility of the proposed approach by measuring the peak signal-to-noise ratio (PSNR) [16]–[18] and structural similarity index (SSIM) between the original and embedded images.
6. Comparison with state-of-the-art techniques: The authors compare the performance of the proposed approach with several existing data hiding techniques, including LSB, DCT, and SVD-based methods, to demonstrate the effectiveness of the proposed approach.
7. Analysis of results: The authors analyze the experimental results to show the advantages and limitations of the proposed approach and provide insights for future research.

Overall, the methodology involves a combination of image processing techniques, texture analysis, and statistical analysis to develop and evaluate the proposed approach for enhancing the robustness and imperceptibility of image data hiding.

5. Quantization Index Modulation

QIM is a watermarking approach that depends on the communication system's side information paradigm, as shown in Fig. 1. According to this platform, an encoder takes a cover signal and a message as input and produces a watermark as an output, which is then added to the original cover signal to produce the watermarked signal. Such a watermarked signal may undergo numerous types of distortion during its passage through the channel. The decoder then receives this combined signal (watermarked + noise signals) and works to re-estimate the watermark.

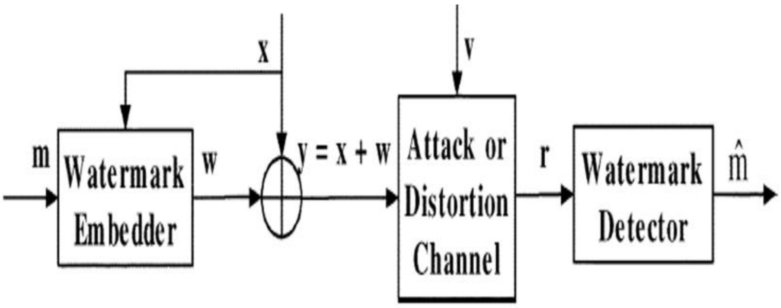


Figure 1: Watermarking as a Communication System [1]

The quantization is done to the input signal, producing a set of reconstruction (discontinuous) points through the rounding of these signal values to the corresponding nearest integer values. The quantization function is given in equation (1).

$$Q(x,\Delta) = round\left(\frac{x}{\Delta}\right)\Delta \tag{1}$$

where, Δ is the quantization step size, and round is the function that maps its argument to the nearest integer [19].

In order to utilize this function in the watermarking field, the straight way to do this is to use dedicated quantization for each watermark digit value. And as the watermark digits in their basic form can be either 0 or 1, two of such quantization functions (i.e., Q1 and Q2) have to be implemented for this purpose. Then the quantization function can be performed based on the embedded watermark digit (m) using the following equation (2).

$$y = Q_m(x,\Delta) \tag{2}$$

6. Dither modulation

Embedding the watermark information into the cover work will, of course, be accompanied by some perceptual distortion. Hence, many works like [20] have relied on a dither mechanism for the sake of mitigating such distortion after conducting the embedding operation. Hence, the embedding process will be conducted utilizing some formulated dither vectors prepared for this purpose. Each watermark's specific digit will depend on one of the corresponding vector values from the vectors for choosing the modulation value. Thereby, the modulation is no longer dependent on the watermark digit. These vectors are designated to be orthogonal to each other to ensure noninterference between the extracted watermark values during the decoding process. Therefore, the watermarking function can be formulated with the assumption of m_n to be the watermark digit, as in equation (3):

$$mrkd_m(C_m, msg_m) = Q(C_m + dthr(m, msg_m), \Delta) - dthr(m, msg_m) \quad (3)$$

Where,

$$dthr[m,1] = \begin{cases} dthr[m,0] + \frac{\Delta}{2}, dthr[m,0] < 0 \\ dthr[m,0] - \frac{\Delta}{2}, dthr[m,0] > 0 \end{cases}, m = 1,2,\dots,n \quad (4)$$

$dthr[m,0]$, $dthr[m,1]$ are pseudorandom values chosen uniformly from vectors with intervals of $[-\frac{\Delta}{2}, +\frac{\Delta}{2}]$ for n of samples. For coded binary dither modulation, the msg_m would be either 0 or 1, as in equation (4).

7. Watermark decoding

On the opposite side of the encoder (namely the decoder side), the watermark digit will be identified utilizing the following equation (5):

$$\widehat{msg}_m = \underbrace{argmin}_{b\in 0,1} (rsv_m - C_r(m,b))^2 \quad (5)$$

where, $C_r(m,b)$ is the reconstructed signal using equation (3) based on the value of b.

This watermark identification function is dependent on embedding one watermark digit in one sample. But in wide applications, specifically spread-spectrum ones, this function can be extended to have one of two forms. The first one is called “hard decision detection,” while the other is the “soft counterpart.” The two functions are given in equations (6) and (7), respectively.

$$\widehat{msg}_m = \left\lfloor \frac{2}{M+1} \sum_{k=(m-1)M+1}^{mM} \underbrace{argmin}_{b\in 0,1} (rsv_m - C_r(m,b))^2 \right\rfloor \quad (6)$$

$$\widehat{msg}_m = \underbrace{argmin}_{b\in 0,1} \sum_{k=(m-1)M+1}^{mM} (rsv_m - C_r(m,b))^2 \quad (7)$$

where, $m = 1,2,\dots,\frac{l}{M}$

This, of course, is applicable for the spread of ${}^{1}\!/_{M}$ repetition rate. The second formula is preferred for making the decision about identifying the watermark digit over the first one.

8. Local variance

One of the most applicable measures for texture analysis is the local variance, which, in contrast to the global one, gives a scalar value for the whole image. The local variance tends to use a sliding window of relatively small size dedicated to finding the mean of the corresponding pixels that lie under this window. As these calculated means for the successive progress of the sliding window are used to reconstruct a same-size image with these means substituting pixels, the remaining step is to apply the following equation (8) to find the local variance of each corresponding pixel, which reflects how each pixel deviates with respect to its neighbors.

$$pixel's\ local\ varinace = E[P^2] - (E[P])^2 \tag{8}$$

Thus, for watermarking applications and according to HVS behavior, it is preferable to give more priority to hiding the watermark in pixels with higher local variance than the others.

9. Distortion Compensation

As the HVS plays an important role in deciding the most qualified regions for watermark hiding, it is possible to exploit it too in deciding to what strength (α) the embedded watermark should be granted. In spite of that, such an increase in strength relative to the most qualified regions can give more robustness to the embedded watermark, but unfortunately, it wouldn’t come without cost. The loss of this increased insertion strength will be at the expense of increased imperceptibility degradation. Therefore, this strength (α) can be adjusted adaptively in order to get a tradeoff between robustness and imperceptibility. By using this strength, some of the quantization distortion can be returned to the original signal in order to mitigate its imperceptibility degradation. The applicable formula for such adaptive embedding is given in (9).

$$\begin{aligned} watermarked &= (1-\alpha)C + \alpha Q_{\Delta}^{b}(C) \\ &= C + \alpha\big(\alpha Q_{\Delta}^{b}(C) - C\big) \end{aligned} \tag{9}$$

where, C is the cover (host) image, α is the embedding strength, Q is a quantization function that rounds its argument to the nearest less or equal integer, Δ is the quantization step size, and b is the watermark bit to be embedded in the host [14].

10. Proposed work

Figs. 2 and 3 below show the proposed schemes for watermark embedding and extraction, respectively.

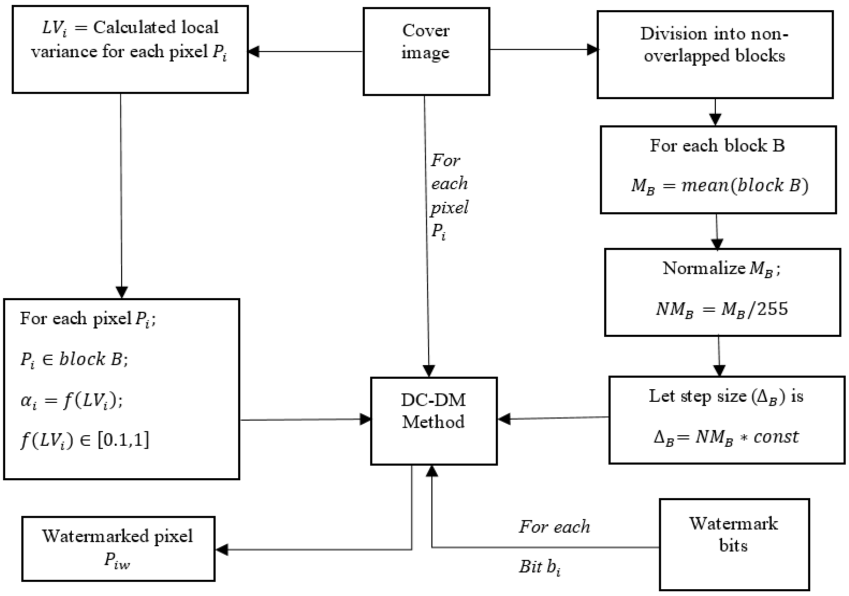


Figure 2: Watermark embedding process

According to the diagram in Fig. 2 for watermark embedding, the cover image undergoes two operations, namely pixel-wise local variance calculation and block-wise cover image division for the adaptive calculations of embedding strength and quantization step size, respectively. The former is intended to evaluate how each individual pixel deviates from its neighbors in an attempt to utilize such deviation for the sake of optimal embedding strength determination based on the pixel qualification with regard to the HVS. Thus, the more deviation there is, the stronger the embedding strength, which is the behavior of the function $f(LV_i)$. The latter is intended to divide the cover image into non-overlapped blocks for the purpose of computing each individual block's suitable step size based on their individual normalized intensity average values. The idea behind using normalization is to make the method resistant to image amplitude scaling, which is a signal processing operation that is usually used as an attack that acts to modify the watermarked image intensity values in an attempt to make non-synchronization between the calculated values of the encoding and decoding quantization step size. The calculated embedding strength and quantization step size are used as arguments for the DC-DM method to carry out the embedding process for each individual watermark bit into the corresponding cover pixels to get the watermarked pixels.

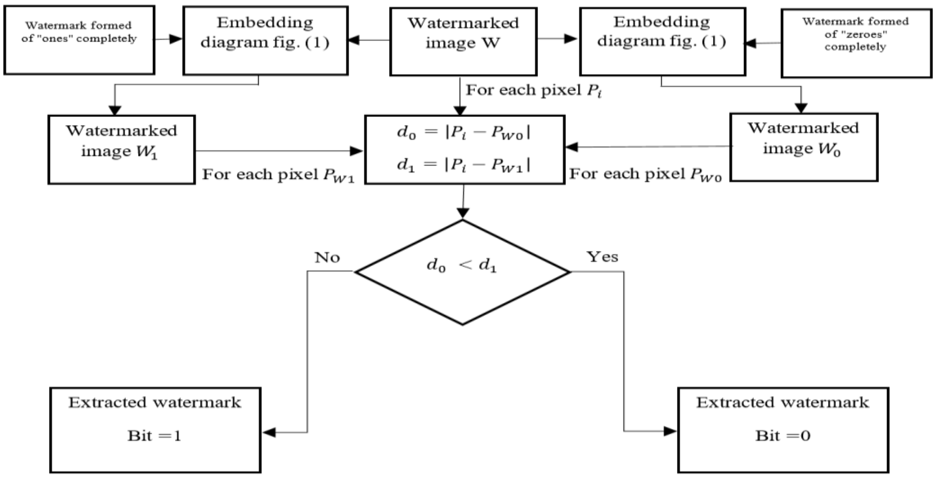


Figure 1: Watermark extraction process.

As shown in Fig. 3, watermark extraction is done by finding the minimum distance for each watermarked pixel from its two modified versions, which are the results of embedding two watermark images separately with this watermarked image, with one of them constituting “zeroes” and the other constituting "ones." The minimum distance of the watermarked pixel P_i to P_{W0} or P_{W1} indicates the presence of a “zero” or “one” watermark bit in the watermarked image, respectively.
The proposed work for "Enhancing Robustness and Imperceptibility with a Texture-Based Adaptive QIM Approach" can be done by first doing the watermark embedding process as follows:

Input: cover image I, secret message M, embedding key K, and other parameters.
Output: Stego image S.

1. Divide the cover image I into non-overlapping blocks of size B x B pixels.
2. Apply the texture analysis method to each block to extract the local texture characteristics, such as texture energy, contrast, and homogeneity.
3. Use the texture characteristics to determine the optimal quantization step size and secret message embedding rate for each block using the texture-adaptive DC-DM method.
4. Embed the secret message M into each block using the DC-DM method with the determined embedding rate and quantization step size.
5. Generate a stego image S by replacing the cover blocks with the embedded blocks.
6. Apply a distortion control mechanism to the stego image S to ensure that the image quality is not significantly degraded. This mechanism can be based on a threshold value for the PSNR or SSIM between the cover and stego images.
7. Encrypt the stego image S using the embedding key K to enhance security.
8. Output the encrypted Stego image S.

The proposed work involves a block-based approach and uses the local texture characteristics to guide the embedding process. The texture-adaptive DC-DM method is used to find the best embedding parameters for each block. This makes the data-hiding process more reliable and hard to spot. The distortion control mechanism is used to ensure that the image quality is maintained within a certain range, which is important for practical applications. Finally, the Stego image is encrypted using a key to enhance security.

While the extraction work of the embedded watermark can be summarized as follows:
Input: encrypted Stego image S.
Output: secret message M.

1. Decrypt the Stego image S utilizing the private key K.
2. Utilizing Stego image S instead of the cover image I, use steps 1–3 of the embedding algorithm to calculate the optimal quantization step size and secret message embedding rate for each block.
3. Normalize the calculated quantization step to be invariant to amplitude scaling.
4. Utilizing the Stego image S and the embedding parameters obtained from steps 2 and 3, make two new Stego image versions, S_0 and S_1, which are embedded by watermarks of zeros and ones, respectively.
5. Use eq. (5) to determine the embedded secret message M in each pixel according to the minimum distance of S pixels from both S_0 and S_1 counterparts.

11. Experimental results

PSNR can be computed for two images (G1, G2) of equal $n * m$ size of 255 grayscales as follows:

$$\mathrm{PSNR}(\mathrm{G1},\mathrm{G2}) = 10\log_{10}\left(\frac{255^2}{\mathrm{MSE}(\mathrm{G1},\mathrm{G2})}\right) \quad (10)$$

where the Mean Square Error (MSE G1, G2) can be computed as [21] [22]:

$$\mathrm{MSE}\ (\mathrm{G1},\mathrm{G2}) = 1/\mathrm{nm}\sum_{i=1}^{n}\sum_{j=1}^{m}\left(\mathrm{G}_{1ij} - \mathrm{G}_{2ij}\right)^2 \quad (11)$$

The greater the PSNR value is, the better the image quality is, and hence a better embedding method [23].

In order to measure the robustness of the watermark, the bit error rate (BER) is used to measure the rate of incorrectly extracted bits of the watermark as compared with the original watermark [24]. This is done by utilizing equation (12) as follows:

$$BER = \frac{incB}{D1 * D2} \quad (12)$$

where, $incB$ is the incorrectly extracted watermark bits, $D1, D2$ are the watermark dimensions [25].

Table 1: Experiment results show the **BER** of the proposed method against various attacks

Attack type	Fixed alpha=1	Adaptive alpha of [0.5,1]
Gaussian blurring attack of 3*3 window and 0.5 std	**0.230**	0.359
Gaussian noise attack of 0.001 variance	0.500	0.500
histogram equalization attack	0.500	0.500
constant change of +1 attack	**0**	0.165
fixed gain attack	**0**	0.006

As can be seen from Table 1, the BER of the fixed alpha method outperforms the adaptive one relatively better. The reverse can be said about the PSNR, as shown in Table 2, but with explicit outperformance in this case. The reason for such cases is that dealing with all regions with the same embedding strength will lead to the clear presence of the embedded watermark digits' influence in the low-textured regions, which leads to some fidelity degradation. On the other hand, utilizing the adaptive embedding strength may decrease these watermarks' negative visual effects in such regions, but at the expense of reducing the watermark digits' ability to stand against attacks.

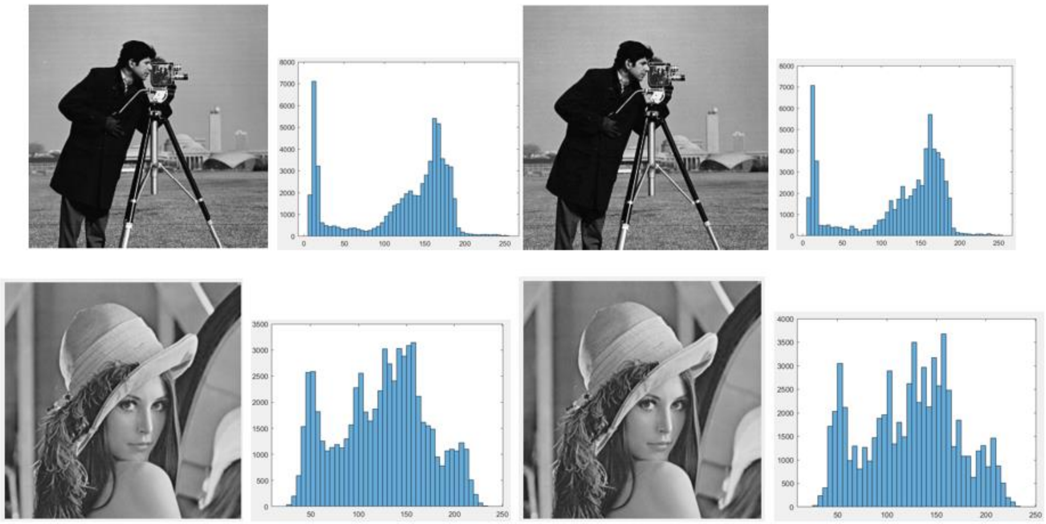
Table 2: Experiment results show the **PSNR** of the proposed method for the fixed and adaptive step size counterparts.

	PSNR	SSIM
Fixed alpha=1	≈ 41	0.925
Adaptive alpha of [0.5,1]	**≈ 46**	**0.976**

The SSIM values of Table 2 show that the adaptive modification of the original image by inserting the watermark digits based on the HVS properties maintains the cover image structure to some extent.

Figure 4: (a) The first column from left includes two instances of original images (cameraman and Lena) of size 256*256; (b) The second column includes their histograms, respectively; (c) The third column includes their watermarked versions; and (d) The fourth column includes these watermarked images' histograms. The watermark is a pseudorandom number of “0” and

“1” bits of size 256*256. below shows the original and watermarked images with their corresponding histograms. This figure shows some minor alterations in the histograms, but in general they keep the same outlets, which means that the proposed method doesn’t affect so much the major image intensity tendency.



(a) (b) (c) (d)

Figure 4: (a) The first column from left includes two instances of original images (cameraman and Lena) of size 256*256; (b) The second column includes their histograms, respectively; (c) The third column includes their watermarked versions; and (d) The fourth column includes these watermarked images’ histograms. The watermark is a pseudorandom number of “0” and “1” bits of size 256*256.

12. Conclusions and future works

Through this work, a scale-independent quantization step size has been proposed as a way to get around the fixed gain attack, which uses a normalized step size based on the average intensity level of the cover/watermarked image. Also, the watermark embedding strength has been determined adaptively to preserve more fidelity while maintaining the required robustness level. In the future, I plan to deal with the signal in the transform domain because it leads to more flexibility in its analysis capabilities [26]. As there are multiple subband levels, the immunity against various attacks can be improved due to the freedom of selecting the most resistant subband to such attacks for embedding. Furthermore, color images can be invested, where some of the color models, like, for instance, YCbCr or HSV/HSI, have intensity components that much resemble the gray images (which are employed in this method) in their nature. Some signal decomposition domains, like singular value decomposition (SVD), can be used to reduce the amount of image data [27] while keeping it as informative as possible. This is one way to meet the time requirements.

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Authors' declaration:

- Conflicts of Interest: None.

- We hereby confirm that all the figures and tables in the manuscript are mine. Besides, the figures and images, which are not mine, have been given permission for re-publication and are attached to the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at Mustansiriyah University.

References

[1] Q. Li and I. J. Cox, "Using perceptual models to improve fidelity and provide resistance to valumetric scaling for quantization index modulation watermarking," *IEEE Trans. Inf. Forensics Secur.*, vol. 2, no. 2, pp. 127–138, 2007, Doi: 10.1109/TIFS.2007.897266.

[2] I. J. I. J. Cox, M. L. M. L. Miller, and A. L. A. L. McKellips, "Watermarking as communications with side information," *Proc. IEEE*, vol. 87, no. 7, pp. 1127–1141, Jul. 1999, Doi: 10.1109/5.771068.

[3] M. Costa, "Writing on dirty paper (Corresp.)," *IEEE Trans. Inf. Theory*, vol. 29, no. 3, pp. 439–441, May 1983, Doi: 10.1109/TIT.1983.1056659.

[4] B. Chen and G. W. Wornell, "An information-theoretic approach to the design of robust digital watermarking systems," in *1999 IEEE International Conference on Acoustics, Speech, and Signal Processing. Proceedings. ICASSP99 (Cat. No.99CH36258)*, 1999, pp. 2061–2064 vol.4. Doi: 10.1109/ICASSP.1999.758336.

[5] J. J. Eggers, R. Baeuml, and B. Girod, "Estimation Of Amplitude Modi cations before SCS Watermark Detection," in *Proceedings of SPIE - The International Society for Optical Engineering*, Apr. 2002, vol. 4675, pp. 387–398. Doi: 10.1117/12.465297.

[6] S. H. Mnkash and M. E. Abdulmunem, "A Review of Software Watermarking," *Iraqi Journal of Science*, vol. 61, no. 10, pp. 2740–2750, Oct. 2020.

[7] M. E. Abdulminuim, "Embedding a Digitized Watermark Upon Colored Image Using Wavelet Transform with Comparative Technique", *Iraqi Journal of Science*, vol. 57, no. 1B, pp. 514–521, Feb. 2023. [Online]. Available: https://ijs.uobaghdad.edu.iq/index.php/eijs/article/view/9253

[8] Q. Li and I. J. Cox, "Using perceptual models to improve fidelity and provide invariance to valumetric scaling for quantization index modulation watermarking," *ICASSP, IEEE Int. Conf. Acoust. Speech Signal Process. - Proc.*, vol. II, pp. 1–4, 2005, Doi: 10.1109/ICASSP.2005.1415326.

[9] J. C. Oostveen, T. Kalker, and M. Staring, "Adaptive quantization watermarking," in *Proceedings Volume 5306, Security, Steganography, and Watermarking of Multimedia Contents VI; (2004) https://doi.org/10.1117/12.526586 Event: Electronic Imaging 2004, 2004, San Jose, California, United States*, Jun. 2004, vol. 5306, p. 296. Doi: 10.1117/12.526586.

[10] Y. Jiang, Y. Zhang, W. Pei, and K. Wang, "Adaptive spread transform QIM watermarking algorithm based on improved perceptual models," *AEU - Int. J. Electron. Commun.*, vol. 67, no. 8, pp. 690–696, Aug. 2013, Doi: 10.1016/j.aeue.2013.02.005.

[11] K. Zhou, Y. Zhang, J. Li, Y. Zhan, and W. Wan, "Spatial-Perceptual Embedding with Robust Just Noticeable Difference Model for Color Image Watermarking," *Mathematics*, vol. 8, no. 9, p. 1506, Sep. 2020, Doi: 10.3390/math8091506.

[12] C. W. Meiling Xu and J. S. Chunxing Wang, Meiling Xu, Wenbo Wan, Jian Wang, Lili Meng, Jing Li, "Robust Image Watermarking via Perceptual Structural Regularity-based JND Model," *KSII Trans. Internet Inf. Syst.*, vol. 13, no. 2, Feb. 2019, Doi: 10.3837/tiis.2019.02.032.

[13] O. Hosam, "Side-Informed Image Watermarking Scheme Based on Dither Modulation in the Frequency Domain," *Open Signal Process. J.*, vol. 5, no. 1, pp. 1–6, Dec. 2013, Doi: 10.2174/1876825301305010001.

[14] M. Li and X. Yuan, "Robust digital image watermarking using distortion-compensated dither modulation," in *Ninth International Conference on Graphic and Image Processing (ICGIP 2017)*, Apr. 2018, p. 112. Doi: 10.1117/12.2302958.

[15] R. Abdulrida, M. E. A-Monem, and A. M. Jaber, "Quantum Image Watermarking Based on Wavelet and Geometric Transformation," *Iraqi Journal of Science*, vol. 61, no. 1, pp. 153–163, Jan. 2020. Doi: 10.24996/ijs.2020.61.1.16.

[16] M. M. Laftah, "3D Model Watermarking based on Wavelet Transform," *Iraqi Journal of Science*,

vol. 62, no. 12, pp. 4999–5007, Dec. 2021. Doi: 10.24996/ijs.2021.62.12.36.

[17] I. I. Hamid and E. M. Jamel, "Image Watermarking using Integer Wavelet Transform and Discrete Cosine Transform," *Iraqi Journal of Science*, vol. 57, no. 2B, pp. 1308–1315, Jun. 2022. [Online]. Available: https://ijs.uobaghdad.edu.iq/index.php/eijs/article/view/7393

[18] L. E. George, F. G. Mohammed, and I. A. Taqi, "Effective Image Watermarking Method Based on DCT," *Iraqi Journal of Science*, vol. 56, no. 3B, pp. 2374–2379, 2015, [Online]. Available: https://www.ijs.uobaghdad.edu.iq/index.php/eijs/article/view/9874

[19] Z. J. Ahmed and L. E. George, "Robust Watermarking for Video Using Mean Modulation Technique," *Iraqi Journal of Science*, vol. 58, no. 4C, pp. 2412–2426, Jan. 2018. Doi: 10.24996/ijs.2017.58.4C.17.

[20] A. Phadikar, "Multibit quantization index modulation: A high-rate robust data-hiding method," *J. King Saud Univ. - Comput. Inf. Sci.*, vol. 25, no. 2, pp. 163–171, Jul. 2013, Doi: 10.1016/j.jksuci.2012.11.005.

[21] N. A. Ali, "Data Hiding in 3D Model Based on Surface Properties," *Iraqi Journal of Science*, vol. 64, no. 2, pp. 973–983, Feb. 2023, Doi: 10.24996/ijs.2023.64.2.39.

[22] S. A. Thajeel, "Robust Video Watermarking of Hybrid Based Techniques," *Iraqi Journal of Science*, vol. 58, no. 4C, pp. 2458–2466, Jan. 2018, Doi: 10.24996/ijs.2017.58.4C.21.

[23] J. H. Awad and B. D. Majeed, "Image Watermarking Based on IWT and Parity Bit Checking," *Iraqi Journal of Science*, vol. 62, no. 8, pp. 2726–2739, Aug. 2021, Doi: 10.24996/ijs.2021.62.8.26.

[24] Y. A. Hassan and A. M. S. Rahmah, "An Overview of Robust Video Watermarking Techniques," *Iraqi Journal of Science*, vol. 64, no. 7, pp. 3613–3624, Jul. 2023. Doi: 10.24996/ijs.2023.64.7.38.

[25] F. Liu, L.-H. Ma, C. Liu, and Z.-M. Lu, "Optimal blind watermarking for color images based on the U matrix of quaternion singular value decomposition," *Multimed. Tools Appl.*, vol. 77, no. 18, pp. 23483–23500, Sep. 2018, Doi: 10.1007/s11042-018-5652-y.

[26] B. D. M. Awad, Jalal H., J. Hameed Awad, and B. D. Majeed, "Moving Objects Detection Based on Frequency Domain," *Baghdad Sci. J.*, vol. 17, no. 2, p. 0556, May 2020, Doi: 10.21123/bsj.2020.17.2.0556.

[27] J. H. Awad and B. D. Majeed, "Overcoming camera instability problem for detecting and tracking moving objects in video using reduced data," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 26, no. 3, p. 1589, Jun. 2022, Doi: 10.11591/ijeecs.v26.i3.pp1589-1598.