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Abstract – The growth of the Internet and online social media, especially in recent years, also gave rise to a proliferation of online multimedia content creation and distribution. The use of modern steganography methods – the art of hiding information within multimedia – presents an unprecedented opportunity for malicious uses of these materials. Therefore, developing an effective technique to avoid the distribution of secret data is a significant problem that is addressed in this paper for digital images. We introduce a novel algorithm to remove the steganography information embedded in an image without changing the quality of the image and with no prior knowledge of the utilized steganography technique. Our new algorithm called Adaptive Threshold Displacement (ATD) is applied to images in the spatial domain. ATD divides the whole image into different segments and within a given segment, some pixels are displaced according to their contents as well as their neighboring pixel values. For evaluating the effectiveness of our proposed algorithm, we apply ATD to different images that contain hidden information, embedded using two different widely used steganography techniques. The presented results show that virtually all of the hidden information is destroyed by our proposed ATD algorithm, with a retrieval BER of over 40% in average. However, the quality of the images does not change and the PSNR of the resulting images is above 32 dB.

Keywords- *Steganalysis, Steganography, Desynchronization, Digital Image, Segmentation, Hidden Information*

I. INTRODUCTION

Hiding information within multimedia data has rapidly been increasing in popularity and research interest over the past few years. The main idea is leverage multimedia files, such as images, audio or video, as a host for embedding secret information within, in such a way that the quality of the media file remains intact and the presence of the hidden information cannot be recognized by anyone other than the intended recipient. This approach is known as steganography and is discussed in numerous publications. While very diverse techniques are proposed to hide secret data in multimedia files, some methods are being developed to detect their existence, often described as passive steganalysis. Instead of focusing exclusively on detecting the existence of hidden information, the techniques used for also extracting the hidden information is known as active steganalysis. Regardless of detecting or extracting stego-data, removing the hidden information from the multimedia files and thus preventing their malicious distribution is another significant approach to be investigated.

This need for steganography removal arises because in the absence of such methods the only approach for network operators in governmental and military environments, or sensitive corporate facilities, is to completely restrict any and all distribution of multimedia material, regardless of whether they contain any hidden information or not. Although this method might prevent the distribution of malicious data, in many instances it is overly restrictive to productivity and general operations. Consequently, researching an effective solution for hidden information removal within multimedia files while preserving the quality of those resources is an important task – and the focus of this paper.

In order to remove hidden information from images, specifically, we could take advantage of different signal processing and geometric manipulations, such as adding noise, applying Gaussian filters, scaling, and cropping of the image. The most important problem of utilizing the mentioned methods is that they do not provide sufficient removal rates for the hidden information. Also their application to images severely deteriorates their quality. In order for these techniques to be more effective, other benchmarks such as [1] and [2] use a combination of geometrical and signal processing manipulations. However, the problem of drastically decreasing image quality still remains. More importantly, there are some steganography algorithms that are resilient against geometric and signal processing changes [3-4].

The main objective of this paper is to present and discuss a novel hidden information removal algorithm that can completely remove the stego-data embedded in an image without having prior knowledge of the embedded technique while preserving the quality of the image.

The rest of the paper is organized as follows: In section II we review related publications and discuss their approaches in hidden information removal, Section III describes our proposed algorithm in detail and provides a discussion of why our method performs effectively. The experimental results are presented in section III and in section IV we present our concluding remarks.

II. RELATED WORK

Over the years, numerous publications have appeared that are related to steganalysis and the removal of hidden information. However, only a few are related to a generic

approach to steganography removal, such as [5-10]. Unfortunately, they each have their own limitations. The authors in [5] proposed two techniques for hidden information removal using local desynchronization. In these methods, the pixels of an image are displaced without considering the content of the pixels, which results in a significant deterioration of the image quality. This arises from the fact that when the pixels are displaced regardless of the contents, some pixels that have considerably different values may be replaced.

Darko et al. in [6] proposed a hidden information removal approach that can be employed for digital images. In this method the multimedia file is divided into overlapping blocks. Then the similar blocks are determined and then substituted with each other. The proposed method in this paper is not applied to images and the case study media files for the illustrated experimental results belongs to the audio files. The proposed algorithm in [7] consists of three stages. In the first stage, Gaussian noise is added to the image. The hidden information is then removed by using an A Posteriori Bayesian denoiser in the second stage. In the third stage the quality of the image is improved marginally by restoring some parts of the original image back to the manipulated one. The presented techniques in [8, 9] are similar to the method in [7] but the second stage is eliminated and in the first stage, a significant amount of noise is added to the image. In these methods due to the fact that hidden information is removed by adding considerable amount of noise to the image, the quality of the manipulated image is affected.

The authors in [10] destroy the synchronization sequence of the hidden information using a resizing approach based on pixel values. This approach scans the image horizontally and vertically and removes or inserts specific low energy blocks in the image. Owing to the fact that the low energy blocks exclusively exist in the images that include flat regions, the effectiveness of this approach highly depends on the type of image content and cannot be applied to all images with sufficient success.

According to our literature review, there are several techniques for hidden information removal. However, to the best of our knowledge there is no method that can completely remove the hidden information while preserving the host file's quality. This is the goal of the algorithm presented in our paper. Utilizing our algorithm, no extra efforts such as applying filters or data restoration from the original image are required to maintain the quality of the image and this approach is applicable to all grayscale and color images.

III. PROPOSED ALGORITHM

In this section we introduce our new algorithm Adaptive Threshold Displacement (ATD) for destroying hidden information based on image content in the spatial domain. Our ATD algorithm can be applied to grayscale images, but also performs well for color images by applying the proposed algorithm to each color channel independently. In

Section A, we provide a brief background of two general techniques of embedding hidden information that is used in most of the steganography algorithms. In section B, we describe our ADT algorithm and discuss our methodology. Section C focuses on the adaptive threshold calculation and defines related terms and relations. In the last section, we describe the PSNR and error calculations which can be used to evaluate the effectiveness of our ATD algorithm.

A. Background

Most of the hidden information approaches are based on either the Spread Spectrum (SS) embedding technique, the Quantization Index Modulation (QIM) technique, or a combination of both approaches. In SS-based algorithms, a random sequence is generated and stored as a secret key that will be used for decoding process later. Then given pixels or transform domain coefficients are chosen within an image based on the generated random sequence to embed stego-data. In QIM-based hidden information algorithms, which also oftentimes called LSB techniques, the least significant bits of an image's pixels or transform domain coefficients are modified for hiding specific stego-data. In order to have an effective approach to embed hidden information within a given image, most of the steganography algorithms take advantage of SS-based methods along with the QIM-based methods to avoid detection and extraction of stego-data. Consequently, removing hidden information from an arbitrary image while preserving the quality of the image is a complicated task to perform.

B. ATD Methodology and General Description

Our proposed ATD algorithm accomplishes the removal of SS-based and QIM-based embedded hidden information at the same time. The main concept behind our proposed algorithm is that any arbitrary image consists of some high-similarity regions, determined according to their neighboring pixel values that can be substituted with each other by swapping all of their values. If the substitution occurs based on the pixel values of the similar regions in addition to their neighboring pixel values, the quality of the image will be preserved and these modifications will not be discernible. However, the displacement of pixels based on specific conditions contributes to changing the spread spectrum sequence. As a result, the secret key for the decoding part of steganography algorithms is desynchronized. Moreover, since the displaced pixel value slightly differs from the original one, the LSB will be affected as well. Therefore, destroying SS sequence and QIM occurs simultaneously. Section C describes the ADT algorithm in details.

For this algorithm, the entire $L = M \times N$ input image is at first segmented into H specific regions of $\{S_1, S_2, \dots, S_H\}$ with $1 \leq H \leq L$ using segmentation algorithms such as [12] or [13]. Each segment consists of R_h pixels of $\{P_1, P_2, \dots, P_{R_h}\}$ with $1 \leq R_h \leq L$. Then, within each segment we consider each pixel as a reference pixel (P_r). The entire segment is scanned to find an appropriate substitution for this pixel in

terms of value. The pixels of each segmented region are assumed to have similar values. This assures that the pixel substitution does not have a deteriorating impact on the quality of the image. A suitable pixel to be swapped with the reference pixel is the one that has the maximum difference of φ_n from the reference pixel. The value of φ_n will be calculated adaptively based on the neighboring values of the reference pixel and will be discussed in section C. Figure 1 demonstrates this algorithm.

Figure 1. Adaptive Threshold Displacement Algorithm

The general procedure of the ATD algorithm is summarized as:

1. Segment the whole image into H regions
2. For all segments:
 - a. For all reference pixels (P_r)
 - i. Consider $I \times J$ matrix and calculate τ based on (2)
 - ii. Calculate the adaptive threshold φ_n based on (4)
 - iii. Find a pixel (P_s) that satisfies (1)

Substitute P_r with P_s

Otherwise, continue.
3. The output is the image that does not include hidden information

C. Adaptive Threshold Calculation and Discussion

In this section we propose a method to calculate the adaptive threshold φ_n used in our ADT algorithm. This threshold is used to find a suitable substitution for the reference pixel P_r . If the reference pixel belongs to a non-flat area of the image, the value of the adaptive threshold will be increased. This results from the fact that insignificant changes of pixel values in non-flat areas are not visually recognizable. However, the displacement of pixels that are in critical regions such as flat areas or the edge of the objects in an image may cause visual distortions. Therefore, the adaptive threshold that is calculated for swapping the reference pixels in the critical regions is decreased. Hence, based on the different regions of an image, we can

adaptively calculate the maximum threshold value that can be used to find an appropriate P_s to be swapped with P_r which satisfies:

$$0 < \|P_r \pm P_s\| \leq \varphi_n \quad (1)$$

To calculate the adaptive threshold, we need to define two concepts. The first one is the accumulative distance between the reference pixel and a specific group of pixels which is defined as τ . For each reference pixel in a given segment, we consider a $I \times J$ matrix of S_{IJ} with elements of $\{\mu_1, \mu_2, \dots, \mu_{IJ}\}$ and we assign the reference pixel as $\mu_1 = P_r$. Also $t = I \cdot J$ where $t \leq R_h$ and the values for I and J are set to $2 \leq I, J \leq 5$. This means that the considered $I \times J$ matrix should be defined inside the segment and cannot exceed the segment dimensions. Based on the defined parameters, the accumulative distance τ can be calculated as:

$$\tau = \sum_{i=1}^t \|P_r - \mu_i\| \quad (2)$$

The value of the accumulative distance depends on the region of the segmented area. For the flat areas, the accumulative distance value is not significant due to the fact that the value of reference pixel is approximately the same compared to the value of its neighboring pixels. Therefore, the adaptive threshold value should be considered low for these regions. However, for the non-flat areas this threshold can increase corresponding to the value of τ . Therefore the value of τ is bounded to:

$$\beta_n \leq \tau \leq \beta_{n+1} \quad (3)$$

Where β_n values vary according to the regions within the segmented image. The minimum value of β equals to zero and belongs to the absolute flat region where the reference pixel value equals to its neighboring pixel values within the matrix S_{IJ} . We define this region as an absolute flat region which is specified as $\beta_{-1} = 0$. We also define a relatively flat region as $\beta_{-1} \leq \tau \leq \beta_0$ where $\beta_0 = 5 \cdot (I \cdot J - 1)$. Then for $n = 1, 2, \dots, (IJ - 1)$ we define:

$$\beta_n = \binom{IJ-1}{n} \cdot 255 + \binom{IJ}{IJ-n} \cdot \frac{\beta_0}{IJ-1} \quad (4)$$

According to the defined regions, we calculate our adaptive threshold based on the accumulative distance which falls into one of the region classes of $n = -1, 0, 1, 2 \dots (IJ - 1)$. Therefore, the maximum threshold that can be used to search for a suitable substitution for the reference pixel is specified by φ_n and is defined as:

$$\varphi_n = \left\lceil \varphi_0 + \frac{\beta_n \cdot t}{\tau \cdot (I \cdot J - 1)} \right\rceil \quad (5)$$

Where φ_0 is the minimum threshold which is assigned to one. This value is used to determine if P_r can be substituted by a given pixel P_s based on the condition (1) which described earlier.

D. PSNR and Error: Calculation and Analysis

We assume that the hidden information that is embedded in an image is labeled as $W = \{\omega_1, \omega_2, \dots, \omega_z\}$ and the extracted hidden information after applying our removal algorithm is labeled as $Y = \{\gamma_1, \gamma_2, \dots, \gamma_z\}$. We can evaluate the capability and effectiveness of our hidden information

removal algorithm by calculating the PSNR of W and Y . In order to calculate the PSNR, the computation of the Mean Square Error (MSE) is required. This value is defined as the average difference between each element of the embedded hidden information and the extracted one. Hence, we can calculate MSE as:

$$MSE = \sum_{i=1}^Z \frac{\|\omega_z - \gamma_z\|^2}{Z} \quad (6)$$

Based on the maximum displacement threshold of the substituted pixels, the maximum MSE can be calculated as:

$$\max(MSE) = \phi_n^2 \cdot \sum_{i=1}^Z \frac{1}{Z} \quad (7)$$

As we can consider that the value of the MSE depends on the total number of the pixels that were displaced in an entire image. Hence, as the number of displaced pixels is increased, the probability of removing the hidden information is improved as well.

IV. RESULTS AND DISCUSSIONS

Our ATD algorithm has been applied to images with steganographically hidden information. These images are grayscale with 512x512 pixels. Our image database contains different types of images such as natural and texture that are used to evaluate the effectiveness of our hidden information removal approach. In this paper, we are showing the results for the stego-data Bit Error Rate (BER) for 10 images out of our image data base. This BER is generated by employing our ATD algorithm to remove the stego-data previously embedded by two prominent steganography algorithms: Wavelet Tree Quantization (WTQ) [10] and Histogram-Based Steganography [11]. The main reasons for choosing these two algorithms are: i) these two algorithms are known as robust and effective techniques for embedding hidden information, with considerable citations in literature, and ii) due to the fact that these algorithms utilize very different approaches for embedding hidden information, the effectiveness of our hidden information removal algorithm will be evident.

In Wavelet Tree Quantization, some of the wavelet domain coefficients are selected and the hidden information is embedded within the image as the quantization level of the given coefficients altered to achieve a specific quantization error.

Alternatively, the Histogram-based algorithm leverages the pixel position invariance of histogram bins. Then, using a method to enforce ratios between neighboring histogram bins for several independent image subsections, the hidden information is inserted. As the results of [10] and [11] demonstrate, these steganography algorithms are robust against geometrical and signal processing modifications, including rotation, different noises and RBA. This means that the hidden information does not significantly change by applying these manipulations to the image and can later still be successfully extracted by the decoding process.

Based on the segmentation algorithm in [13], most of the images are segmented into 4 or 5 regions. Within a specific region, all the pixels are scanned and, based on their

neighboring pixel values, the threshold for replacing these pixels with a new value is changed adaptively. This threshold will increase based on its 3x3 neighboring pixel set. The number of hidden information bits that are embedded into the case study images is 200 bits for both histogram-based and wavelet tree quantization algorithms. Sections A and B discuss the results of removing the hidden information from an image that is embedded using wavelet tree quantization and histogram based algorithms, respectively. Section C compares the effectiveness of our proposed approach of hidden information removal by comparing its results to those obtained via signal processing and geometrical manipulations.

A. Hidden Information Removal Results of Images with Wavelet Tree Quantization Steganography

In this section we are presenting the results of applying ATD to images from our test set. The first example, shown in figure 2a, is the Elaine image. The figure shows the image before (on the left) and after (on the right) of applying our ATD algorithm to the image. The image on the left has previously been processed by the steganography algorithm to embed hidden information. Both images appear virtually identical, showcasing the high visual similarity and low impact on quality of our ATD algorithm.

Figure 3 shows the results of applying this algorithm to 10 test images out of our test set. As we can see from this figure, we achieved an average stego-data BER of more than 45%. In other words, the hidden information is virtually irrecoverable. The PSNR of 33dB also indicates that no

a) ATD hidden information removal algorithm results for wavelet tree quantization steganography

b) ATD hidden information removal algorithm results for histogram-based steganography

Figure 2. ATD hidden information removal algorithm results. (left images: images containing hidden information, right images: after removal using our ATD algorithm)

perceptible image quality impact occurred due to the application of ATD to the images. This is due to the pixel similarities within regions and the limitation of not changing region edge pixels.

As mentioned before, in general, wavelet tree quantization steganography chooses specific wavelet tree coefficients and modifies the LSB of the selected sequence to embed the hidden information [10]. The main reason for the effectiveness of the ATD algorithm in hidden information removal is that by substituting given pixels within a segmented image the values of wavelet domain coefficients are altered as well as their location. Hence the LSB value of the coefficients and the sequence key are not the same. Consequently, the hidden information cannot be extracted.

Figure 3. ATD results for removing hidden information embedded by Wavelet Tree Quantization

B. Hidden Information Removal Results of Images with Histogram-based Steganography

The boat image on the right side of Figure 2b illustrates the output image after employing our ATD algorithm on the input image, shown on the left, which was previously processed by a Histogram-based steganography algorithm to embed information. We can once again observe the close visual match of both images.

Figure 4 provides the results of applying the ATD attack to the same 10 images chosen from our test set. For this test, however, the hidden information is embedded using the histogram-based approach. Once again we achieved the stego-data BER of over 36% to 40% while ensuring image quality with an average PSNR above 33dB. As a result of applying ATD, the histograms of image subsections changed to such a degree that the algorithm's hidden

information extraction process [11] is unable to do so successfully.

As shown in Figures 2 and 4, our ATD algorithm successfully destroys the hidden information within the images due to the fact that by image pixel displacement the values of local groups of pixels are modified. Consequently, the spread spectrum synchronization sequence and the histogram of the image will be different. Moreover, the visual quality of the image is not considerably changed which arises from substituting the pixels according to the pixel values in addition to the values of neighboring pixels.

Figure 4. ATD result for removing hidden information embedded by histogram-based steganography

C. Comparing our ATD Removal Approach to Signal Processing and Geometrical Attacks

In this section, we compare our ATD algorithm to some of the prevailing geometrical and signal processing modifications that have the theoretical potential to remove the hidden information within an image. These modifications include rotation by 1 degree, 4x4 median filtering, JPEG compression, resizing by 30%, cropping by 15%, as well as Gaussian and Poisson noise. We employ these manipulations against the same image test set containing hidden information embedded utilizing wavelet tree quantization and histogram-based algorithms. As the authors demonstrated in [10] and [11], the wavelet tree quantization and histogram based steganography algorithms are resilient against the geometric and signal processing modifications and even after applying these modifications, the hidden information can be retrieved and extracted. We summarize the results in Table 1 as the average BER and

PSNR over the 10 test set images also shown for Figures 3 and 4.

Table 1. ATD hidden information removal results compared to signal processing and geometrical manipulations for 10 natural images of 512x512 with 200 embedded hidden information bits.

Hidden Information Removal Approach	Wavelet Tree Quantization		Histogram	
	Image PSNR	Stego-Data Bit Error Rate (%)	Image PSNR	Stego-Data Bit Error Rate (%)
Rotation by 1°	29.16	32.6	28.31	26.5
Median Filter 4x4	28.37	26.5	27.19	29.75
JPEG	39.92	21.6	41.15	17.5
Resizing (30%)	29.71	36.7	29.3	39.4
Additive Gaussian Noise	27.25	12.6	27.47	11.5
Poisson Noise	28.31	24.4	28.04	28.5
Cropping (15%)	31.24	21.5	32.18	19.6
Proposed Algorithm - ATD	33.52	47.2	33.015	40.042

V. CONCLUSIONS

In this paper we have presented a novel hidden information removal algorithm called Adaptive Threshold Displacement (ATD) that can be applied to grayscale and color images in the spatial domain. Our proposed algorithm can eliminate virtually all of the hidden information within an image, regardless of the steganography approach that is used for embedding the hidden information, with negligible impact on the image quality. ATD divides the image into specific regions using segmentation algorithms. The pixels within each region therefore exhibit value similarities that ATD uses to displace pixels within each region, with the exception of pixels close to the region's edge. Displacement of the pixels is based on their neighboring values and the adaptive threshold which is calculated accordingly. The adaptive threshold may increase depending on the neighboring pixel values. We evaluated our ATD algorithm by applying it to images that include hidden information embedded using wavelet tree quantization and histogram-base steganography techniques. These two algorithm classes provide the foundation for a wide range of steganography approaches. According to the demonstrated results, our new approach of removing hidden information functions effectively by achieving a stego-data BER of more than 40% in average. Furthermore, ATD does not have a significant impact on image quality, as the PSNR is consistently more than 31dB. This results from careful modifications in the image through the pixel displacement within the segmented image by also considering the values of the neighboring segments. The substitution of the pixels within the image segments achieves desynchronization of spread spectrum embedding and the distortion of quantization-based embedded. Therefore, ATD can very effectively be utilized to destroy hidden information within

images embedded using spread spectrum, QIM, or a combination of both methods.

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