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A Review on Reversible Data Hiding Techniques

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Abstract

Data hiding is an art, which involves the technique of carrying a data in a suitable multimedia carrier for secure communication. Data hiding techniques provide secret communication and authentication but can cause a loss of the carrier. These techniques are used for copyright protection, media registration, integrity authentication etc. Applications like medical imagery, military and forensics degradation do not allow distortion of original cover. So it needs secure data hiding techniques. To overcome this disadvantage of extracting the carrier with distortion was removed by reversible data hiding methods. Reversible data hiding techniques recovers the original carrier exactly after the extraction of the secret encrypted data. Reversible Data Hiding Techniques are classified based on the method of implementation. In this paper a survey on the different techniques applicable based on difference expansion, histogram shifting and compression embedding, for reversible data hiding are discussed.

Keywords: Reversible Data Hiding, Difference Expansion, Histogram Shifting, Compression Embedding, Prediction Error.

INTRODUCTION

Digital Steganography and Watermarking are two primitive techniques for communicating secrete data in suitable carriers like image, audio and video files. These techniques may distort the original image after extracting the hidden data. These can be used for copyright protection, media registration, integrity authentication etc. The embedding process usually distorts the original cover image that carries secret data permanently. But in applications of medical image processing, military and forensics, degradation of original cover cannot be allowed. To overcome this disadvantage a method that can recover the original image without distortion after the extraction of the secret data came into existence. It was known as reversible data hiding (RDH) or lossless data hiding. It embeds invisible data known as payload or secret or hidden data into a digital image known as cover image in a reversible manner. Figure 1 shows the block diagram of RDH.

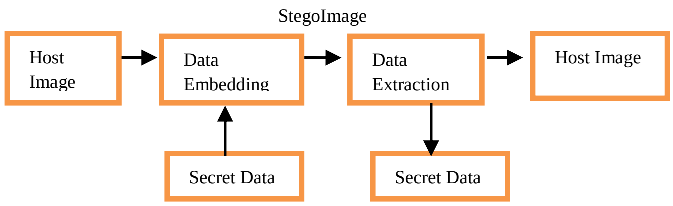

Figure 1: Reversible Data Hiding

Reversible Data Hiding restores original image after the extraction of the secret data with negligible distortions and fair quality. Hence RDH techniques are getting popular.

From a secure communication system's view RDH embeds some digitized information in an image so that only an authenticated party can extract the hidden information and restore the original image. An information hiding system can be characterized based on four different aspects:

Capacity refers to the quantity of hidden information the cover media can accommodate.

Security refers to the feature included to protect the extraction of the hidden information by a hacker.

Perceptibility is the ability to notice the hidden information.

Robustness is the ability to withstand modifications on the stego medium without distorting the hidden information.

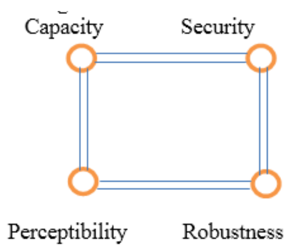

Figure 2: Characteristics of Reversible Data Hiding

Standard RDH algorithms are basically classified into three. The first category of algorithms follow lossless compression-embedding framework (LC)[1]. In it, a twin feature is computed for a pair of pixel and compressed. Messages are embedded in the extra space left by lossless compression. The second categories of algorithms are based on difference expansion (DE)[2]. Here pixel pair differences are expanded to get the least significant bits (LSBs) all-zeros so as to be used for embedding messages. The last RDH algorithms are based on histogram shift (HS)[3]. The histogram of an image, which is uneven, can be modified for embedding data by considering the bins of histogram.

Almost all RDH methods include two steps [4]. First, a host sequence with small entropy is generated usually using predicted errors (PE). In the second step, messages are reversibly embedded into the host sequence by modifying the histogram using DE or HS. These result in payload maximization in a given distortion condition or overall distortion minimization for a given payload.

Among these, the HS based methods are most popularly used. HS based methods can be further divided into three different approaches, i.e., histogram shifting (HS)[3], difference histogram shifting (DHS)[5], and prediction-error histogram shifting (PEHS)[6]. Nowadays, DHS and PEHS methods are popular due to their huge embedding capability and high fidelity. A number of DHS and PEHS based algorithms were proposed in the past few years [5]– [8]. In all these methods the main idea is to generate a difference or prediction error histogram using the correlation between the neighboring pixels in a host image. On modifying the difference or prediction histogram the host image is reversibly embedded with the message.

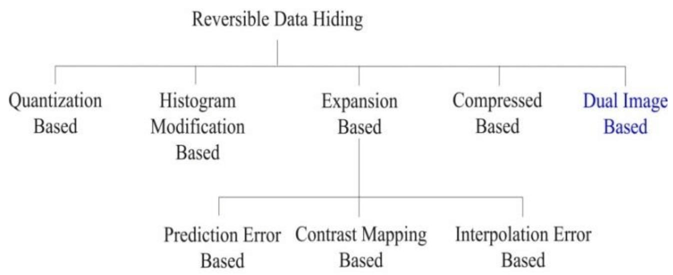

Figure 3: Classification of RDH

LITERATURE REVIEW ON RDH

Reversible Data Hiding has been existing since years. Researchers have come up with different RDH methods to improve the above said characteristics. This section illustrates RDH methods, which have been proposed over years till date.

Traditionally reversible watermarks were initiated as a visible pattern by Mintzer *et al*. in [9]. Images marked with reversible visible watermark were posted on the Internet for application in their digital library. The watermarked image was in the form of a puzzle that the users could obtain easily using a program for an extra fee, removing the watermark and thus reconstructing the original image. The Eastman Kodak [10] was the first to own a patent of lossless invisible watermarks. Reversibility was certified by a modulo operation added to the existing additive method. The same idea was being proposed in [11] to extend the patchwork algorithm [12]. However, the results were not acceptable. These methods caused “salt-and-pepper” visual artifacts. Magnitude comparisons were used to retrieve watermarks, which failed in images that caused visual artifacts. To overcome these problems, Fridrich et al. [13] proposed to modify a bit plane of the image for watermarking. They extracted a complete bit plane and losslessly compressed for filling the watermark payload in the resulting space. This method had an occurrence of disturbing artifacts due to the varying number of bit planes as the capacity changed from image to image. Fridrich’s method worked strictly for environments where, if a watermarked image was lossly processed resulting in a bit modification, the bitplane containing the payload will disturb the entropy synchronization thus losing the hidden data permanently. Vleeschouwer et al. [14] proposed a method that overcame Fridrich’s method [13]. They made use of circular interpretation of bijective transformations. A circle was mapped with the histograms for groups of pixels that was operated by the transform. The relative orientation among the histograms of two groups conveyed one bit of information. Here the reversibility process did not experience artifacts and the wrapped pixels were not altered.

[15]- [21] illustrates difference expansion transforms. Tian [15] was the first to use a difference expansion transform. It was applied on a pair of pixels to develop a low distorted high-capacity reversible watermark. The algorithm divided the image into pixel pairs that did not cause an overflow or underflow. Then a single bit was embedded into the difference of the pixel pair. The payload included a compressed location map mentioning the modified pairs. This method resulted in embedding as high as 1/2 bits/pixel in a single pass. Alattar[16]used vectors of an arbitrary size as parameter to difference expansion transforms. The algorithm resulted in a computationally efficient higher capacity embedding with little image distortion. Wang et.al.[17] suggested the usage of 2D-vector maps for RDH. They discovered two reversible data-hiding difference expansion schemes. In the first scheme, the coordinates of vertices were the cover data and altering the differences among the neighboring coordinates was used to hide data. The second scheme calculated the Manhattan distances between the neighboring vertices as the cover data and embedded the hidden data altering the differences among the neighboring distances. Both schemes resulted in high capacity maps with highly associated coordinates. The authors of [18] discussed a spatial domain reversible watermarking scheme based on the contrast mapping (RCM). This resulted in high-capacity data embedding without any secondary compression stage. The space occupied by the LSBs is used for data hiding. Difference expansion transforms were concentrated for improving RDH characteristics [19]- [21].

[22]- [32] illustrates the advancements of histogram shifting. The zero or the minimum points of a histogram was utilized by slightly modifying the grayscale value of the pixel for RDH in [22]. It resulted in embedding large amount of data and accomplishing higher PSNR. A different approach for RDH was tried out in [23] based on histogram modification technique. It used differences between pixels thus increasing hiding capacity. A binary tree was used to remove the requisite of communication between pairs of zero and peak points to the recipient. Jung et. al. [24] made use of a data embedding level. It was adjusted for every pixel depending on human visual system characteristics. For reducing the distortions, the embedding level was determined by the

estimated values based on an edge and the slightly differential values of each pixel. [25] Generalized the method used in [24] using a decompression algorithm. This algorithm embedded data using a coding scheme. It aimed for predefined entropy to be reached using a compression algorithm by reaching the rate distortion bound for the generalized code. It succeeded. Using these binary codes, three RDH schemes- one for spatial images, one for JPEG images, and a pattern substitution scheme for binary images that used binary feature sequences as covers were improved.

In [26], for independent identically distributed gray-scale host signals, the proposed method asymptotically approached the rate-distortion bound of RDH until a perfect compression was realized. This method resulted in the equivalency between reversible data hiding and lossless data compression. To facilitate the design of RDH, one just needs to define the shifting and embedding functions [27]. In [28], RDH was accomplished based on two-dimensional difference histogram modification by using difference-pair-mapping (DPM), an injective mapping defined on difference-pairs. First, a sequence consisting of pixel differences is computed by taking each pixel-pair and its context into consideration. Then, taking the frequency count of the resulting difference-pairs generates a 2D histogram. Thus, reversible data is embedded according to the specifically designed DPM. Better image redundancy and improved performance was the result when compared with the previous one-dimensional histogram based methods.

Prediction error expansion (PEE) for RDH was proposed for multiple histograms [29]. Sequences of histograms were used based on multiple histograms modification (MHM) to devise a new embedding mechanism. A prediction error histogram (PEH) is generated based on complexity measurement for each pixel according to its context. The result was minimized embedding distortion, fixed modification manner, high PSNR and independence of image content. [30], [31] enhanced the contrast of a host image thus improving the visual quality keeping PSNR high. This was accomplished by histogram equalization on the highest two bins in the histogram. With this method the original image was completely recoverable. Based on JPEG encoder and quantized DCT coefficients, [32] presents RDH. Here a new histogram shifting based RDH scheme for JPEG images was proposed, where the zero coefficients were unchanged and coefficients with values 1 and −1 were expanded to carry the hidden message.

[33]- [39] illustrates prediction error. Vasiliy et.al proposed [33] RDH using sorting and prediction. Prediction errors were used by an image to embed data. For recording this prediction error based on magnitude of its local variance a sorting technique resulting more data with low distortion compared to previous methods was introduced. Lixin et.al. proposed [34] RDH using interpolation technique resulting in preserving the quality of image even after adding the hidden data. It used the variance among interpolation value and the corresponding pixel value for embedding bits. In PEE based RDH, performance can be better accomplished by exploiting image redundancy. The prediction errors by Bo et.al [35] are modified individually for data embedding. A sequence prediction-error pairs was generated by two adjacent perdiction errors. Based on this sequence and the resulting 2D prediction error histogram, RDH is performed resulting in improved performance. Xiaocheng et.al [36] proposed a PEE based on the minimum rate criterion for RDH establishing the consistency between a prediction error histogram generated by utilizing pixel prediction strategies and the process of embedding secret data into these prediction errors through expansion and shifting of these histograms. This method was outstanding in terms of prediction accuracy and embedding performance.

Bin et.al [37] designed a code division-multiplexing algorithm for RDH. The covert data was represented by different orthogonal spreading sequences using Walsh Hadamard matrix and embedded into the cover image. The original image could be completely retrieved exactly after the data was extracted. Multilevel data embedding enriched embedding capacity. Yingqiang et.al in [38] proposes a RDH method using generalized integer transformation (GIT). While hiding data into the original image, parameters of the extended GIT are identified related to the content of each block. The embedding algorithm makes use of these GIT parameters. A better embedding efficiency for a given payload is achieved using a multi-level location map.

Haishan et.al[39] proposed a directional enclosed predictor inorder to detect the locations where local complexity(LC) is not proportionate to PE. A directionally enclosed prediction and expansion (DEPE) scheme also was then developed for efficient reversible data hiding. The advantage of using DEPE showed that data embedding was restricted to pixels where LC correlated to PE with a proportional relationship.

[40]-[47] illustrates lossless compression methods for RDH. A method for high capacity low image distortion embedding with less complexity was developed by Celik et al. [40]. Here the least significant bits were overwritten for embedding the information bits. Chin et.al [41] suggested a RDH for the lossy image format using SMVQ (side match vector quantization). The SMVQ-compressed cover image contains the secret data in such a way that attackers cannot detect the presence of the secret data in the stego-image. As the SMVQ compression codes could be reassembled even after the hidden data was extracted, the communicating parties were enabled to share the cover image. As a continuation of the SMVQ technique, Yi-Pei et.al [42] proposed RDH for embedding data in VQ-compressed codes formed on the basis of the declustering strategy and the similarity property of neighboring areas in a normal image. They proposed two declustering methods, one using the minimum spanning tree and the second using short-spanning-path algorithms. With this proposed method original cover index table could be recovered from the stegoed index table. Here the embedding capacity depended on image context, codebook size, and the number of the declustered groups.

A new concept of sequential quantization strategy (SQS) was introduced in [43]. Here the alteration of a host was made supported on a certain number of the earlier ones. Thus a balance between security improvement and tamper localization could be achieved for integrity verification. This resulted in making of authentication applications. In [44] a balance between reversibility and distortion was tried to achieve by a RDH scheme based on invariability among the sum of pixel pairs and pairwise difference adjustment (PDA). Here for each pixel pair, the policy used was, when a certain value was added to one pixel and the same value was subtracted from the other, the sum of these two pixels remained unchanged. Zhenxing et.al [45] suggested method targeting at encrypting a JPEG bit stream into an appropriately ordered structure, and then embedded a secret message into this encrypted bit stream by marginally modifying the JPEG stream. The secret message bits were encoded using the error correction codes to attain a complete data extraction and image recovery. Inorder to overcome the control the huge size of location maps Vasiliy et. al [46] proposed RDH taking the HVS characteristics of an image into consideration.

KokSheiket. al. introduced RDH in videos [47]. Information was implanted into a compressed video by concurrently manipulating Mquant and quantized DCT coefficients, the significant parts of MPEG and H.26x-based compression standards. When fed into an ordinary video decoder, the modified video can reconstruct the original video even at the bit-to-bit level. Reverse zero run length (RZL) was used to deed the statistics of macroblock for realizing high embedding efficiency trading off the payload.

The necessity for secure communication is challenging. Hence the concept of RDH methods for encrypted images has evolved. RDH method for encrypted images can be classified into two categories: 1) vacating room after encryption (VRAE) and 2) vacating room before encryption (VRBE) [48].

RDH in encrypted image was initially introduced in [49] by Xinpeng. Here the original image encrypted by a stream cipher was used to embed the secret data. In this method, the hidden data was extracted successfully and the original image was claimed completely using the spatial correlation feature of the original image. From the prior scheme Xinpeng further extended a concept of separable RDH in Encrypted Image [50]. In this method, usage of keys was introduced. In the embedding phase, the owner of the content to encrypt the original uncompressed image uses an encryption key. Then LSB of the scrambled image is compressed using a data-hiding key creating a sparse space to accommodate extra data by the data hider. In this method there are three possibilities that can happen in the encrypted image containing hidden data: 1) when the receiver has the data-hiding key, then he can extract the hidden data without knowing the image content. 2) when the receiver has the encryption key, then he can decrypt the received data to get an image similar to the original one, but cannot extract the hidden data 3) when the receiver has both the data-hiding key and the encryption key, then he can extract the hidden data as well as recover the original content precisely without loss provided the hidden data is not too big. Xinpeng's scheme did not utilize the pixels completely in analyzing the smoothness of each block as well as the pixel associations in the border of neighboring blocks were not considered. So Wien [51] introduced a new smooth-evaluation function that fully exploited the pixel blocks for estimating the pixel variations in images. A side-match mechanism was also presented to analyze the smoothness of those confusing blocks.

In [52] a novel method of merging art image generation and data hiding to develop the camouflage effect for different information-hiding presentations was proposed. The author used a line-based Cubism-like image, maintaining the characteristics of the Cubism art in which prominent lines and regions did abstraction from multiple viewpoints. Here data hiding with slight alteration was carried out expertly in the procedure of recoloring the regions of the created art image by shifting the pixels' colors for a slight amount keeping the average colors of the regions unaffected. In [53], another way of encryption based on value alteration iteratively under a payload-distortion standard was used for the RDH. The hidden data, along with the supporting information was used for content retrieval by finding out the variances between the original pixel-values and the values assessed from the neighbors. The estimation errors were altered according to a optimal value transfer rule.

[54] Projected a path-following algorithm to evaluate the best spectrum of the marked-signal for implementing RDH. A novel technique was proposed [55], which automatically converted a set of large-sized secret image into a hidden-segment-visible mosaic image of similar size. This mosaic image, which looked similar to a arbitrarily selected target image was used as a camouflage of the hidden image. Separating the secret image into fragments and converting their color features to those of the equivalent blocks of the target image generated the mosaic image. [56] Presented an innovative RDH scheme, using contrast enhancement that improved the PSNR from the previously got values. Usually when large numbers of bits are inserted, image contrast becomes over-enhanced, introducing distortion for human visual perception. It used controlled contrast enhancement (CCE) and Haar integer wavelet transform (IWT). Initially, a proper image contrast enhancement was attained into the image in spatial domain during the data-embedding phase by observing the contrast improvement pointer. It showed that the adjustment of the subband coefficient details in IWT domain produced only slight contrast changes. This lead to inserting more data into the detail subbands without dropping the visual quality meaningfully.

The system proposed in [57] included three parties: the content owner, the data-hider, and the recipient. The content owner is the one who encrypts the original image and uploads it onto a remote server. The data-hider is the one who divides the encrypted image into three groups embedding message into each group generating marked encrypted image. The recipient is the one who extracts this message using an extraction key. Using this method nearly good quality image could be obtained on decryption if the receiver has a decryption key. When both keys are available, the original image can be losslessly recovered. In [58] RDH in encrypted images using distributed source coding was implemented. After the content owner using a stream cipher encrypts the original image, the data-hider compresses a series of selected bits taken from the encrypted image to make room for the secret data. The selected bit series is Slepian–Wolf encoded used low-density parity check codes. [59] Proposed a new RDH scheme over encrypted domain. Data embedding was attained through a public key alteration mechanism, where the secret encryption key was not accessed. At the decoder side, a two-class SVM classifier was used to distinguish between encrypted and nonencrypted image spots as well as to decode the embedded message from the encrypted image. The authors in [60] exploring the correlation between neighbor pixels, proposed to consider the patch-level sparse representation for hiding the secret data. The extensively used sparse coding technique proved that a patch could be linearly represented by some bits in an over-complete dictionary. As the sparse coding was an approximation solution, the principal outstanding errors were scrambled to self-embed the hidden data and the learned dictionary within the cover image.

In order to achieve RDH in scrambled domain, patterns have been considered according to encryption algorithm utilized by [61],[62]. The pixels in a basic image are first separated into sub-blocks with the size of m × n. Then, with an encryption key, a key stream consisting of random or pseudorandom bits/bytes that can be merged with a plaintext stream to generate the encoded message was generated. The pixels in the same sub-block were encoded with the same key stream byte. After the stream encryption, the encrypted m × n sub-blocks are randomly permutated with a permutation key. As the association between the neighboring pixels in each subblock could be well conserved in the encoded domain, most of the formerly proposed RDH schemes could be applied to the encoded image directly.

RDH has included the usage of cloud communication, which is being evolved popularly. In [63] a framework for RDH-EI(encrypted image) based on reversible image transformation (RIT) was proposed. Unlike the earlier encryption schemes where cipher texts attracted the probing cloud, RIT-based framework allowed the operator to convert the content of original image into the content of another image of the same size. The converted image, that seemed to be the target image, was used as the “encrypted image,” by the cloud. Another work using the cloud was implemented by the authors in [64]. They proposed RDH scheme where the cipher text images were scrambled by public-key cryptosystems with probabilistic and homomorphic properties. In this scheme, the cipher text pixels were substituted with new values embedding the hidden data into different least significant bit planes of cipher text pixel using multilayer wet paper coding. The embedded data was then separated from the encrypted domain successfully.

CONCLUSION

Reversible data hiding techniques recovers the original carrier exactly after the extraction of the secret encrypted data. Applications like medical imagery, military and forensics use these techniques for copyright protection, media registration, integrity authentication etc. The different techniques used for reversible data hiding over the last two decades like lossless compression, differential expansion, histogram shifting, prediction error and its variations were discussed. All the above techniques were improvised and implemented for better results in terms of capacity, perceptibility, robustness and most importantly security. The more challenging thread of RDH is RDH in encrypted images where data can be hidden in encrypted images vacating room after encryption (VRAE) and 2) vacating room before encryption (VRBE) and RDH in cloud computing was also discussed.

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