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Athena: capacity enhancement of reversible data hiding with consideration of the adaptive embedding level ☆

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ABSTRACT

This article provides a novel method of reversible data hiding (RDH) by adaptively adjusting the embedding level to achieve minimal distortion and to attain the embedded data confidentiality via data reversion key generation. The peak point queue (PPQ) is used to adaptively determine the embedding level and achieve superior quality in the marked image. In respect to data reversion key for the double protection, our approach, named Athena, makes better utilization of the overhead information and allows users to exchange the key based on a public key infrastructure (PKI). Our experimental results show that the method is capable of providing a better quality image for a range of different test images of various sizes.

1. Introduction

In the current explosion of the information era, there is a significant volume of data being exchanged between people. So far, there are several techniques that can protect data and prevent modification, such as encryption, signatures, and watermarks. We may encrypt personal information and exchange them with other people, yet in the case of public work, this is not viable. It has the same problem as the signature technique. However, we not only need protection, but also some notation to indicate our ownership and detect whether or not it has been modified [1]. A simple technique is a stamp to declare that the author is authentic, yet we have to make the stamp invisible without changing anything. Data hiding is the most typical technique.

Data hiding embeds minimal data into an image for rights protection, authentication, secret sharing, etc. It is used in military images, medical images, artwork, law enforcement, and document preservation. In general, the reversible data hiding (RDH) method embeds secret data into an image and then publishes it. In order to verify the image, RDH extracts secret data to confirm whether or not it is modified. In other words, RDH is able to extract secret data from a marked image and recover the original image without any distortion. RDH techniques can be applied to various multimedia contents (such as images, text, audio/video and software) in trusted devices where image integrity is critical to the applications. For instance, a trusted digital camera with RDH technique could properly preserve evidence to make it suitable for a trial. In the case of medical images, the quality of the image (less distortion) is essential. Thus, trusted RDH devices should hold integrity with the goal of providing publicly available images as well as preserve the quality of the image (less distortion). A high value of peak signal-to-noise ratio (PSNR) means better image quality. In gray-scale image applications, if RDH had PSNR that exceeds 30 dB, the

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human visual system could not detect any distortions [2,3]. Furthermore, in artwork protection, a watermark is embedded for ownership protection [4]. It is necessary to recover the original artwork after the watermark is extracted.

The method of data hiding with reversibility has the advantage of being able to recover the cover image without distortion, yet its hiding capacity is limited [5]. To obtain reversible data hiding with a higher hiding capacity and maintain good quality images, a histogram-based scheme using pixel differences was proposed [4]. The generated residual image was then employed to embed the secret data. The residual histogram of the values in the marked image was calculated according to the secret data size, using a binary structure to satisfy the requirements adaptively and exchange pairs of peaks with the recipient as well. Upon completion, a histogram shifting technique prevents overflow and underflow [6]. The advantages of the basic histogram approach [4] are simplicity and low distortion. However, the peak point value influences the quality of the marked image. In this article we will present a peak point queue (PPQ)-based technique, named Athena, to maintain the same hiding capacity while achieving a higher quality marked image. Athena allows adjustment of the value of the peak point with the requirement of the secret data size. Further, the data reversion key is generated after completion of the embedding process in order to secure marked image distribution. A single image corresponds to a unique key. Upon authenticating the identity of the receiver, the sender transmits the key. The receiver can then extract the message using the corresponding key.

The remainder of this article is organized as follows. In Section 2, we review the reversible scheme developed earlier. Section 3 contains a detailed explanation and derivation of the proposed algorithm. We experimentally investigate the relationship between the capacity and distortion in Section 4. The article concludes in Section 5.

2. Related works

An RDH method is one where an embedded message can be extracted and the image completely restored to its original state. RDH techniques may vary depending upon the technology, but they need to fulfill several considerations: marked image quality (PSNR, used to measure the degree of image distortion); payload capacity (bits per pixel, bpp, used as the performance metric for the degree of hiding capacity); overhead information (the amount of data required associated with the marked images to decode the hidden secret data); security (the ability to resist any intentional attack to removal, embedding and detection of the marked images).

According to [7,8], RDH techniques could be classified into the following categories: lossless compression-based scheme [9,10], histogram approach [5,6,11], difference expansion [12], prediction error expansion [13,14] and two-dimensional histogram approach [15]. The basic concept of lossless compression-based scheme is to compress a feature set of cover image to save the space for embedding data [9,10]. However, lossless compression-based scheme is not able to provide big payload capacity due to the nature of the correlations among a bit-plane.

The histogram-based reversible data hiding technique was proposed by Ni et al. in 2006 [5], who proposed a reversible data hiding algorithm which is now considered a significant step forward in the data embedding research area. They used the zero point and peak point of the histogram of an image and slightly modified the pixel values to embed secret data into the image. In the embedding process, they searched the peak and zero points and then shifted the histogram in order to generate free space to embed data. Only the peak points were used to hide data while the others were only modified. Their work is guaranteed to have a peak signal-to-noise ratio (PSNR) above 48 dB. Although Ni et al. managed to achieve a short execution time and a high PSNR value, their work suffers due to its low hiding capacity.

Tai et al. [6] proposed a reversible data hiding scheme based on histogram modification of pixel differences. They used a binary tree structure to store the communication pairs of peak points. In the pre-processing stage, they used the pixel difference to consider the difference between adjacent pixels instead of a simple pixel value, and adapted the histogram shifting method to prevent overflow and underflow of the image. Due to the use of the pixel difference techniques, they are able to find more free space to hide the secret data in the cover image (a.k.a. original image). They claimed that their work can provide a large hiding capacity while minimizing distortion. However, the PSNR values drop rapidly according to their experimental results. This is a major flaw that we wish to address in our work.

Lee et al. [11] proposed a reversible image authentication technique which is based on histogram modification similar to Ni et al. [5], and claims to provide lower distortion. In their work, they used the difference-histogram techniques which are not regular in shape and provide a much higher peak point. The difference-histogram techniques are generated by projecting into the two-dimensional histogram which are the odd- and even-line fields. The secret messages are embedded in the odd-line field by calculating the value of the pixels. They also used the MD5 as a hash function in order to produce a 128-bit array as output. In their experimental results, the Lena image's PSNR was 52.21 dB and the capacity was 26900 bits. This shows that their capacity is quite small, and is unsuitable for modern applications.

Tian [12] proposed a novel difference expansion approach utilizing expandable differences to provide spare space for embedding and exchangeable differences to guarantee blind data extraction. In 2007, Thodi [13] introduced the prediction error expansion approach, an improved version of difference expansion. Thodi applied the difference histogram obtained from the cover image and predicted image to describe the statistical expandable difference distribution. Based on the concept of the prediction error expansion, some better prediction algorithms with the adjustment of the embedding level (peak point value) to enlarge hiding capacity. For instance, Tsai et al. [2] proposed a reversible image hiding scheme based on histogram shifting for medical images, and is based on the