A One-Dimensional Technique for Embedding Data in A JPEG Color Image

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Abstract—**A method of embedding data in a JPEG color image for applications such as authentication of an employee carrying a picture identification card is described. Embedding of data, such as key biometric or other unique identification information of the person, is carried out by modifying the spectral power at a pair of one-dimensional frequencies. These frequencies may be selected arbitrarily for each block of image and for each color in the one-dimensional version of the image. Preliminary results show that the 1-D spectrum modification technique causes barely noticeable distortion in the embedded image if a moderately high sampling rate is chosen for the converted 1-D signal. Using an oblivious technique and a key consisting of the frequencies where spectrum is modified, successful data retrieval with no bit errors has been achieved. Results show that an embedded image corrupted by low level noise still retained the hidden data with low bit errors.**

Keywords – **Data embedding, image, spectrum modification**

I. INTRODUCTION

Data embedding employing a host image is a useful means for storing or hiding information, and for covert transmission or steganography. Information is hidden in a cover image in such a way that the embedded image (the stego) is indiscernible from the unembedded host, or cover image. By concealing information imperceptibly in the cover image and using a strong key, attempts at illegal recovery and/or tampering of hidden data are foiled. An imperceptible embedding technique that can also accurately recover the embedded information and without requiring the cover image, i.e., by an oblivious method, can be used in secure or covert communication [1].

Another key application area of image embedding is in hiding vital medical or biometric information of employees in their pictures for ready access in case of an emergency, or for secure identification [2, 3]. In these applications, biometrics-based identifying information, for example, may be hidden in the picture card of a person and the claimed identity of the card carrier can be verified by retrieving the hidden data and comparing them with the biometric data collected on the spot. A small amount of distortion in image quality in such applications may be tolerable as long as data robustness is guaranteed. Watermarking of images and video for compliance of digital rights management applications, on the other hand, requires spreading of a small amount of data so that imperceptibility is assured. While imperceptibility is also critical for covert communication, data robustness and payload are vital in personnel authentication applications with, preferably, oblivious data extraction.

We present a method of embedding data in a color image that requires a key for retrieval. Image distortion causing visibility of embedding is minimized at a cost of lower payload, with the embedded information spread throughout the image. This method is proposed as an extension to prior work on spectral domain audio embedding by tone addition [4 – 6] and gray level image embedding [7], both using spectral domain modification.

II. IMPERCEPTIBLE AUDIO EMBEDDING IN THE SPECTRAL DOMAIN

Imperceptibility of embedding data in an image can be achieved by exploiting the imperfection in the human visual system, which has lower detectability of patterns in the presence of other patterns at close frequencies. Based on the results of secure embedding in the spectral domain of audio signals, the proposed technique for image embedding relies indirectly on the masking property of the human visual system. In the case of audio embedding at psychoacoustically masked audio frequencies, a pair of auditorily masked spectral points that are common to all, or most, of the frames of the cover audio signal are set in a known ratio of amplitudes [4]. A bit of 1 or 0 is embedded in a frame with the spectral amplitude ratio set at above or below one, respectively. Since the two selected frequencies *f1* and *f2*, in general, may not be present in all frames, spectral amplitudes are set at low values relative to the average power of each frame.

Retrieval of embedded data is carried out by the spectral amplitude ratio at *f1* and f2 of each of the received quantized frames. Results of this procedure for audio cover signals showed imperceptible embedding with accurate data retrieval. Additionally, the spreading of embedding due to spectrum modification caused little noticeability in the absence of the original cover audio. Because of these advantages, the spectrum modification procedure was extended to image embedding in [7] using a black-and-white image. By converting the pixel data to a one dimensional signal – by appending pixel rows sequentially – and evaluating the masked frequencies in each frame of 64 pixels, the two most commonly occurred audibly masked frequencies were used for spectrum modification and embedding. This procedure resulted in low visibility of embedding and accurate data retrieval that required no original cover image. Extension of this procedure to a JPEG-compressed color image in one or two colors also produced successful embedding and correct data retrieval [8]. In the present work, we describe a modified embedding procedure by selecting two arbitrary, instead of masked, frequencies, and also an arbitrary frequency for the sampling rate of the converted 1-D signal.

III. IMGAE EMBEDDING IN THE SPECTRAL DOMAIN

Although the choice of sampling rate for the converted 1-D signal of image pixels is arbitrary, a higher rate can result in more spectral points for modification with better frequency resolution. This is particularly significant if embedding is carried out at an arbitrary pair of frequencies instead of those that are in the masked region of visibility in a majority of frames. For a selected sampling rate of *fs* and *N*-point DFT for spectrum evaluation, there are, potentially, be *N/4* pairs of points available for modification. A pair of spectral points may be selected for modification for each frame. Embedding (and retrieval) key then consists of the ordered set of selected pairs of spectral points for the frames of the image. To minimize the size of the key, one pair may be chosen for each color. At each pair of the selected points *f1* and *f2* for a given color – red, green or blue – the spectrum may be modified imperceptibly as follows.

To embed a 1:

$$X'(f1)=\alpha . e^{i\theta_1} \quad X'(f2)=\beta . e^{i\theta_2} \tag{1a}$$

To embed a 0:

$$X'(f2)=\alpha . e^{i\theta_2} \quad X'(f1)=\beta . e^{i\theta_1} \tag{1b}$$

where $X'(f1)$ and $X'(f2)$ are the modified spectral components at frequencies *f1* and *f2*, and θ_1 and θ_2 are the phase angles of the original spectrum at *f1* and *f2*. The scaling constants α and β are adapted based on the average power of each segment. Typically, α is larger than β so that the spectrum at one of the two frequencies is higher than that at the other frequency. Both values, however, are small enough so that they are not visible in the spectrogram of the audio signal and large enough to be not lost in quantization after embedding. The values for α and β may be set empirically for a given cover image, if both values are small. By retaining the same phase as that in the original spectrum at *f1* and *f2*, no phase-related distortion is introduced after modification. Modified frame spectrum is transformed to time domain, quantized to the same number of levels as the cover image, and converted back to two-dimensional image.

Embedded information in each segment is recovered using the spectral ratio at the two (key) frequencies, *f1* and *f2*. That is, the recovered bit *rb* in a segment (image block) is given by

$$rb = \left\{ \begin{array}{l} 1, \text{ if } \left| \dfrac{X(f1)}{X(f2)} \right| > b1 \\ 0, \text{ if } \left| \dfrac{X(f2)}{X(f1)} \right| > b0 \end{array} \right\} , \tag{2}$$

where *X(f)* is the spectral component of the frame (block) at cyclic frequency *f*, and *b1* and *b0* are set empirically. If a frame is left unembedded for added security or when the data size is smaller than the available capacity, spectral levels at the two frequencies are set equal; this corresponds to a retrieved bit of -1.

Security of the key can be enhanced by using a different pair of embedding points *f1* and *f2* for each frame from the available list of *N/4* pairs. Illegal retrieval and/or tampering of data by an exhaustive search of all DFT points is, therefore, made harder to accomplish as each frame requires a complete search of *N/4* pairs of frequencies.

IV. RESULTS AND DISCUSSION

The procedure outlined in the pervious section was implemented on a JPEG-encoded color image (kid.jpg) of size 289X200 pixels, shown in Fig. 1. The 1-D signal was obtained by concatenating rows of pixels starting from the top for each color. An arbitrary sampling rate of *fs = 16,000 Hz* and a frame length of 64 samples (from linear rows of pixels) were used in the first experiment. At a DFT size of 256 (for a frequency resolution of 62.5 Hz), DFT points of 79 and 101, which correspond to *f1= 3750 Hz* and *f2=5625 Hz*, were selected for embedding by spectrum modification. The scaling constants were set at $\alpha = 1$ and $\beta = 1\text{E-}5$ of 10 percent of the root-mean-square (RMS) value of each frame. Use of the frame RMS value adapts the spectrum modification to low enough levels for perceptibility.

Figure 1. Original (cover) image.

To test the visibility of modification, an extreme case of embedding one bit each in all of the 903 (= 289x200/64) frames was carried out. The result, with only one color modified and two colors (red and blue, red and green or green and blue) modified, which doubled the embedded data capacity to 1806 bits, showed very little visibility; when all three colors were modified (tripling the payload to 2709 bits) using the same pair of frequencies and scaling constants, the modified image exhibited somewhat noticeable difference with the original image. While the detectability of embedding may cause problems in covert communication and steganography applications, it may not be significant in the picture identification document of an employee carrying unique identification in the picture. More important in such an application is the ability to accurately extract the hidden information. All the cases of spectrum modification stated above caused correct retrieval of the embedded data. Fig. 2 shows the image of Fig. 1 after modifying all three colors to carry a bit of 1 in each of the 903 frames. Although the pair of frequencies were arbitrarily chosen, unlike in [8], the small changes in the spectral magnitude at these frequencies contributed to low visibility of embedding. Histograms in each color showed no difference compared with those of the original image.

A lower sampling rate of $fs = 10{,}240$ *Hz*, was chosen in the second experiment with $f1 = 4840$ *Hz* and $f2 = 5000$ *Hz* (DFT indices 122 and 126) for all three colors. The embedded image obtained for this case is shown in Fig. 3. Here again, all 1806 bits were recovered correctly from the quantized pixels after spectrum modification. Visibility of embedding appears to be similar to the case of using the higher sampling rate of 16000 Hz.

Figure 2. Embedded image after modifying spectrum in all three colors using $fs = 16{,}000$ *Hz*, and $f1 = 4840$ *Hz* and $f2 = 5000$ *Hz*. Data = 2709 bits of 1.

Figure 3. Embedded image using $fs = 10{,}240$ *Hz*, and $f1 = 4840$ *Hz* and $f2 = 5000$ *Hz*. Data = 2709 bits of 1.

To study the effect of noise on data retrieval from the embedded image, (a) Gaussian noise, or (b) salt-and-pepper noise was added after spectrum modification in each case. Gaussian noise with zero mean and a low variance (below about 0.001) caused low bit errors in red and green colors, with the blue color resulting in as high as 30 bits flipped out of 903. Fig. 4 shows the noise-added embedded image of Fig. 3. Salt-and-pepper noise at a density of 0.005 added to the embedded image with 903 1's in each color, shown in Fig. 5, caused bit errors of between 13 and 37 out of 903.

While lossless conversion of an embedded image to JPEG format retained the data without any bit error, lossy JPEG compression resulted in significant bit errors in retrieved data. This problem is under investigation along with other improvements to the proposed technique.

Stego + G Noise

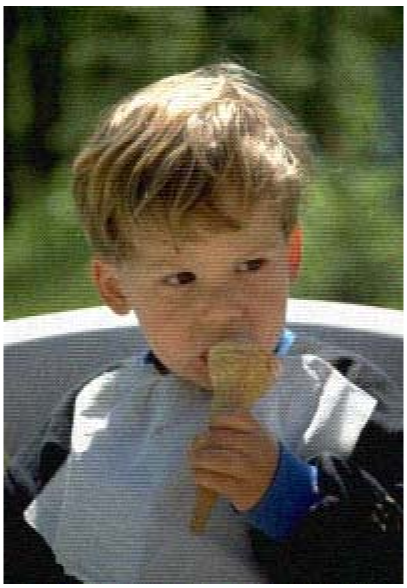

Figure 4. Gaussian noise added to the embedded image of Fig. 3.

V. Conclusion

A method of embedding data on a JPEG color image by converting the image to a one-dimensional signal in each color has been proposed. By altering the one-dimensional spectrum of each segment of a cover image at two key frequencies, embedding becomes barely noticeable. Hence, the technique is dependent on the cover image for perceptual masking of spectrum modification. Availability of a choice of frequencies for the key at which the spectrum is modified renders the hidden data impervious to unauthorized access. Another advantage of the technique is that the hidden information is extracted by an oblivious method. The proposed method can be used to embed authorization information in the picture of an employee in access control applications. Choice of 1-D sampling frequency can also be varied in these applications for added security of different employees. Low level noise added to simulate scanner performance in user authentication applications caused low bit errors in recovered data. These errors can be minimized by replicating the data at low payload.

Stego + S&P Noise

Figure 5. Salt--and-pepper noise added to the embedded image of Fig.3.

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