A TECHNIQUE FOR IMPERCEPTIBLE EMBEDDING OF DATA IN A COLOR IMAGE

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Abstract: A method of embedding data in a color image for applications such as authentication of an employee carrying a picture identification card is described. By converting the color image to a one-dimensional signal in red, green, or blue, audibly masked frequencies in the 1-D signal are determined for each segment or block. Embedding of data, such as key biometric information of the person, is carried out by modifying the spectral power at a pair of commonly occurring masked frequencies. Preliminary results show that the spectrum modification technique is simple to process and causes barely noticeable distortion in the embedded image. 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. Embedded image corrupted by low level noise still retained the hidden data with low bit errors. Higher payload of hidden data can be obtained at a cost of perceptibility of embedding.

1 INTRODUCTION

Data embedding employing a host image is a useful means for storing or hiding information. Information is hidden in a cover image in such a way that the embedded image (the stego) is indiscernible from the unembedded 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 without requiring the cover image, i.e., by an oblivious method, can be used in covert communication (Petitcolas, et al, 1999).

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 (Wu and Liu, 2003). A small amount of distortion in image quality in such applications may be tolerable as long as data robustness is guaranteed. While imperceptibility is 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 perceptibility of embedding is minimized at a cost of lower payload. This method is proposed as an extension to prior work on spectral domain audio embedding by tone addition (Gopalan, et al 2003) and gray level image embedding (Gopalan, 2006), both using spectral domain modification.

2 SPECTRAL DOMAIN EMBEDDING

Imperceptibility of embedding data in an image can be achieved by exploiting the imperfection in the human visual system (HVS). 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 HVS. In the case of audio embedding at psychoacoustically masked audio frequencies, a two step procedure has been reported (Gopalan, et al 2003). In the first, a set of auditorily masked spectral points for each frame of a given cover audio signal is determined. These frequencies depend on the just noticeable difference (JND) in hearing and a

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global masking threshold based on a set of critical band filters.

Modification of the spectrum is carried out in the second step by setting the power levels at the two masked frequencies in a known ratio for bits 1 and 0. The pair of frequencies and the power ratio of the two masked spectral components (and the frame indices, if only a selected frames carry hidden data) form the key for embedding and retrieval of data. Average power levels set to one-tenth and one-hundredth of the segment power at masked frequencies has been observed to result in inaudible and robust hiding of information. Since spectral domain modification at the two frequencies is at relatively low power levels and it is spread across all time samples in a segment, the embedded (stego) audio is rendered imperceptible from the original (cover) audio in waveform, spectrogram and audibility.

Extension of spectrum modification at selected frequencies for image embedding and its implementation are described in the following sections.

3 IMAGE SPECTRUM MODIFICATION PROCEDURE

To extend the above two-step audio embedding algorithm for hiding data in an image, a common pair of visually masked spectral points can be determined using psychovisual contrast or pattern masking frequencies from the discrete cosine transform (DCT) of each block of an image. Alternatively, a simpler one-dimensional approach, similar to the determination of psychoacoustically masked frequencies for an audio signal, can be used in place of detecting the JND in the image. This approach can be further simplified by converting the two-dimensional intensity level of a color host image in one of the three primary colors to one-dimensional signal by appending all the rows (or columns) sequentially. (It has been shown that by treating each block of 8x8 subimage as a frame (by conversion to one-dimensional data) of 'audio' and appending all the blocks together causes noticeable distortion in the image after spectrum modification (Gopalan, 2006).

Choosing a high enough 'sampling frequency,' a pair of most commonly occurring masked frequencies in all frames (of typically 64 pixel samples each) are obtained by determining global masking threshold and setting an acceptable level of spectral density below this level for each frame. (Although the choice of sampling frequency is empirical, a high value – above 10,000 Hz – gives more masked frequencies, which contribute to a stronger key for embedding and retrieval.) Spectral power levels at the selected pair of frequencies in each frame are set by a known ratio for embedding binary values. An advantage of this conversion and embedding is that it entails less computational effort and faster detection of embedding points compared to a DCT-based procedure.

A pair of most commonly occurring masked frequencies *f1* and *f2*, in part, form the key for embedding and retrieval. Complex spectrum at each of the two frequencies is modified to attain imperceptibility of embedding. Since the two audibly masked frequencies may not be present in all the segments, raising their power levels based on the global audio masking threshold for a given frame may result in discernibility of embedding in the overall audio and, hence, image. To prevent this, power levels at *f1* and *f2* are set to low levels in each segment. If X(f1) and X(f2) are the spectral components at frequencies *f1* and *f2* in the original segment, the spectrum-modified (i.e., data-embedded) segment is obtained as follows.

To embed a 1:

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

To embed a 0:

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

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 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 (histogram) of the audio (image) signal and large enough to be not lost in quantization after embedding. The values for α and β are set empirically for a given cover image.

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

$$rb = \begin{Bmatrix} 1, \text{ if } \left| \dfrac{X(f1)}{X(f2)} \right| > b1 \\ 0, \text{ if } \left| \dfrac{X(f2)}{X(f1)} \right| > b2 \end{Bmatrix} \qquad (2)$$

where *X(f)* is the spectral component of the embedded and quantized frame at cyclic frequency *f*, and *b1* and *b2* are set empirically. If a segment 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.

The key for embedding and retrieval consist of the indices of the embedded frames and the corresponding frequency pair used to modify spectrum. This key, clearly, depends on the cover image. Both the variability and the presence of many masked points make it harder for illegal retrieval and/or tampering of data by an exhaustive search of possible embedded frequencies.

4 IMPLEMENTATION AND RESULTS

Results of the two-step image embedding algorithm using the gray scale cameraman image (cameraman.tif) available in MATLAB showed that embedding at a pair of high frequencies, even though they are not the most commonly occurring masked frequencies, caused little noticeable distortion and zero bit error in data recovery (Gopalan, 2006). Based on these results, the technique was applied to embedding data in one or more of the primary colors in a JPEG color image. This image (kid.jpg) of 289x200x3 pixels was converted one-dimensional signal in each of the three colors by appending all the rows of pixel values together. Using an arbitrary sampling frequency of 16,000 Hz, the masked frequencies for each color were obtained. The pair of frequencies, 4875 Hz and 6250 Hz, which were in the masking set of approximately 30 percent of the segments for all three colors, resulted in minimal distortion of embedded image with each of the three colors. For the size of 289x200 = 57800 values in the one-dimensional signal, a maximum of 57800/64 = 903 bits can be embedded when all the frames of 64 pixels each are used.

To test the image quality with this full capacity, (a) all bits of 1, (b) all bits of 0, and (c) a random set of 903 bits, were used each for the data with the constants α and β set at a ratio of 1E-5 from the average power of each segment. The resulting image for (a) is shown in Figure 1 along with the original cover image. Using a spectral ratio of *b1* = *b2* = *1* in Eq. (2), all the embedded bits were retrieved correctly from the modified and quantized image. Perceptibility of embedding, as can be seen from the figure, appears to be minimal. Same results in data recovery were observed for the other two cases as well. Image distortion was more noticeable for green and red colors relative to modifying blue, however, due to lower sensitivity of HVS to small changes in blue than to green or red.

Extending the embedding procedure to more than one color using the same pair frequencies showed a slightly noticeable distortion in the image. Figure 2 depicts the image resulting from modifying spectrum in the color pair red-blue. (Although, for simplicity, the same frequency pair has been used in all the cases, the key can be made stronger with different frequency pairs for each case.) Visibility of embedding appeared to be more for green-blue modification than for red-green; red-blue pair showed the least distortion in image quality. As with the single color modification, this is due to the higher threshold of HVS in perceiving changes in red and blue. With a total of 2x903 = 1806 bits, the doubling of payload can be exploited for embedding data of larger sizes. Considering that the payload is doubled, the distortion may be tolerable in pictures such as in a driver license, for example.

Altering the spectrum at the same pair or, at different pairs, of frequencies at all three colors tripled the payload at a cost of higher visibility. Since data recovery caused no bit errors, the increased payload can be used to strengthen the key by selecting frames for embedding, which can also reduce image distortion.

5 CONCLUSION

A method of embedding data on a color image by converting the image to a one-dimensional signal in each color, or more than one 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. Availability of a choice of frequencies

Original

(a)

Stego, Blue with all 1's

(b)

Figure 1: (a) Original host image, and (b) Image with blue color carrying 903 bits of 1's.

(for the key at which the spectrum is modified) renders a strong key and makes the hidden data impervious to unauthorized access. Another advantage of the technique is that the hidden information is extracted by an oblivious method; hence, the proposed method is suitable for transmitting embedded information using any cover image regardless of its availability at the receiver. Additionally, the proposed method can be used to embed authentication information in the picture of an employee.

Stego, R & B

Figure 2: 2 Modifying spectrum in red and blue colors.

A key question that arises from the proposed method is the lack of correlation between audibly masked frequencies and the JND in each image frame. Another is the choice of an appropriate sampling frequency in the conversion so that an embedded image is indistinguishable from its original cover image. Since there is no relationship between the audibility of a masked tone frequency and the visibility of a masked pixel, the implicit assumption in going from one-dimensional (audible) to two-dimensional (visible) domain may not always result in imperceptible embedding. The simplicity of the proposed technique, therefore, must be weighed against these questions.

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