Smuggling Secret Messages in JPEG Images

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Abstract

The conspicuous nature of encrypted messages can accidentally disclose the existence of a secret discussion. This study examines a technique for stealthily incorporating encrypted messages into JPEG compressed images. The suggested system achieves a significant level of covert communication by embedding the encrypted message within the image data without introducing any perceptible changes to the visual appearance of the image. Beneath the guise of an ordinary image lies a hidden message, waiting to be deciphered by those with the key.

1. Introduction

The practice of encrypting messages is well-known. It can be done for example, in order to pass a financial data[1]. The goal of this paper is not showing how such an encryption can be done. There is a lot of discussion about this issue. Our aim is showing how such a message can be smuggled in a JPEG image. Hiding a message can be very efficient in a financial or a martial community. A third person, who listens to the transmission, can think that just an innocent picture was transfer. This third person will not even try to break the code, because he will think there is no secret message in this message.

JPEG[2,3] images are saved as sets of frequencies. These frequencies are not accurate. They use to be saved as approximate values. Actually, some numbers divide the values. Then, the values are rounded, so the values can be saved in a less space. This approximation gives JPEG the ability of compressing images efficiently. These inaccurate values are very similar to the original values. It is very hard to notice where did JPEG change the original data. Taking one more step is using the least significant bits of the frequencies values in order to save an encrypted message. The value of the sequence will be changed slightly, but again this change will be very hard to be distinguished.

The new message which will be sent, is much longer. Apparently, this is a disadvantage of this method. However, Such a price may be worth, if being hidden, is very important for the message. Nowadays, when communication lines become much more faster, this disadvantage will become much less significant. Downloading JPEG images from the web is a very common action. We can see that this action doesn't consume a long time; so sending a JPEG image won't be a conspicuous deficiency.

2. The JPEG standard

One of the basic classical applications of imaging technology is to represent images as a set of pixels. Each pixel is defined by a numerical value, and is separately manipulated. There are many ways to store image data without degrading the original data. Some of these ways lose part of the data, but it usually isn't noticeable. For example the BMP[4] standard is a well known format for image storage without data compression, while the GIF[5] standard is a well known format for image storage which uses the LZW[6] algorithm for compressing the image's data.

The JPEG is a well known standardized image compression. JPEG is algorithm, which loses information, meaning that the decompressed picture isn't the same as the original one. By adjusting the compression parameters process, we can adjust the degree of loss. Why use JPEG? There are two principal reasons: to reduce your image files, and to store full color information.

Reducing images files is an enormous reason for transmitting files across networks and for archiving libraries. JPEG will usually be able to compress images meaningfully, which produces a huge difference in disk space and transmission time. Unfortunately, even with a JPEG viewer, it takes longer time to decode and view a JPEG image than to view an image of a simpler format such as GIF, BMP, etc.

The second principal advantage of JPEG is that it stores full color information: 24 bits/pixel or 16 million colors. In other hand, the GIF format widely used in the Internet network, can only store 8 bits/pixel or 256 colors.

Here is a brief overview of the JPEG algorithm:

The first step transforms the image color into a suitable color space. There are several methods to transform the image into a color space [7,8]. The most common methods are the split into RGB components[9] or the split into YUV components[10]. These components are intertwined together. The ration between these parts is usually not one by one. When YUV components are used, usually The Y component will grow to 4 times its weight. The reason for doing this is that the human eye is less sensitive to high frequency chrominance information than to a high frequency luminance which is represented by the Y component in the YUV format [11].

The second step groups the pixel values into 8X8 blocks. Then, transform each block through a Forward Discrete Cosine Transform (FDCT)[12]. The DCT gives a frequency map, with 8X8 or 64 elements. The reason for doing this is that you can now erase high frequency information without affecting low frequency information. The DCT coefficients are composed of a single Direct Current (DC) coefficient number, which represents the average intensity level value in each block or a blocky approximation of the image and the remaining 63 are named Alternating Current (AC) coefficients. The 63 AC coefficients are ordered into a zig-zag sequence which sorts them into a one dimensional array of increasing spatial.

The next step is the *quantization*. In each block, we divide each of the 64 frequency components by a separate "*quantization coefficient*", and round the results to smaller integers. Furthermore, we note that even in the case of the quantization coefficient is 1, we lose some piece of information, because the DCT coefficients are typically real numbers.

The last step, encodes the reduced coefficients using either Huffman[13] or Arithmetic coding[14]. Usually a strong correlation appears between DC coefficients of adjacent 8X8 blocks. Therefore, the baseline JPEG model uses two different Huffman trees to encode the data, one for the DC coefficients' length and the other for the AC coefficients.

The JPEG space is defined by a space with three types of coefficients members field, the DC coefficient’s field, the encoded AC coefficients field, and the End Of Block (EOB) field to symbolize the ending point.

Finally, all the compression parameters are written in the headers so that the decompressor module can reverse the process. JPEG's philosophy is summarized in Figure 1.

The decompression process performs an inverse process. First, it decompresses Huffman or Arithmetic codes. Second, it performs the inverse process of the Quantization process, which was done by compression process. In this stage it raises the small numbers to larger numbers, which are close to the original numbers, of the DCT coefficient. The last stage is doing an Inverse Discrete Cosine Transform (IDCT) on the data received from the previous stage.

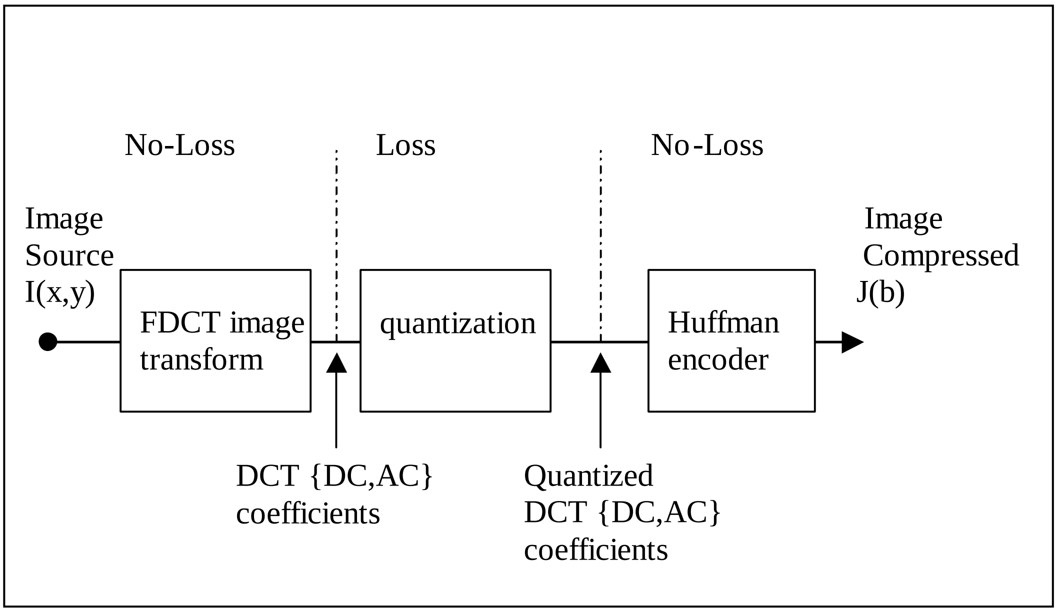

Figure 1: JPEG Model for lossy image compression

3. The smuggling algorithm

In the JPEG format the source image samples are grouped into 8X8 blocks, shifted from unsigned integer to signed integer, and input to Forward DCT. The following equations are summarized the mathematical definition of the $N \times N$ (FDCT) and $N \times N$ (IDCT).

(1) $F(u,v)=C(u)C(v)\left[\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f(x,y)*\cos\frac{(2x+1)u\pi}{2N}\cos\frac{(2y+1)v\pi}{2N}\right]$

(2 $f(x,y)=\left[\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} C(u)C(v)F(u,v)*\cos\frac{(2x+1)u\pi}{2N}\cos\frac{(2y+1)v\pi}{2N}\right]$

Where: $C(u), C(v)=\begin{cases}\sqrt{\frac{1}{N}} & for \quad u=v=0 \\ \sqrt{\frac{2}{N}} & otherwise\end{cases}$

The DCT-based compression can be viewing the FDCT as harmonic analyzer and the IDCT as harmonic synthesizer. In the case of JPEG format each 8X8 block of the source image samples is effectively a 64-point discrete signal which is a function of the 2D dimensional space *x*, and *y*. The FDCT takes such a signal as its input and decomposes it into 64 orthogonal basis signals. The output of the FDCT is the set of unique 64 basis signal amplitudes, which can be regarded as the relative amount of the 2D spatial frequency contained in the 64-point input signal.

The results of these mathematic formulas are treated as integers. Moreover, some numbers divide these integers and the results again are accommodated in integers. Obviously, rounding floating-point numbers to integers causes some loss of data, so the values of JPEG's coefficients are not accurate. The smuggling algorithm exploits the fact that the values are not accurate anyway. It changes the least significant bits of the values so they will not contain a data of an image. These bits will contain an encrypted message.

The smuggling algorithm takes into account some or all of the following considerations:

- **The quality of a picture**

JPEG standard stipulates that a user can set the quality of the picture when he creates it. More qualitative image consumes more disk space. The quality value is a number not less than 100. This value sets the numbers which divide the AC coefficients. When a smaller number divides an AC coefficient, more data will remain, so when reconstructing the image, the data will be more accurate and a better picture will be seen.

When using more qualitative image, the smuggling algorithm can insert more bits. Almost every time a high quality image is used, the added data is redundant. The smuggling algorithm can take advantage of this redundant data. It can replace the redundant data by an encrypted message.

- **Coefficients might be changed.**

Human's eye is more sensitive to first coefficients. Indeed, smaller numbers divide the first coefficients, when JPEG does the quantization step. On the other hand, because smaller numbers divide the first coefficients, they may have more data, which can be used by the smuggling algorithm.

The smuggling algorithm must take into account, the size of the compressed data. JPEG treats the data as sequences. Each one of these sequences contains a sequence of zeros and another value at the end. When there are just zeros left in the end of a block, JPEG puts an EOB. It is very common to find a block from a JPEG image with an EOB after about 20 coefficients or so. The rest of the coefficients after the EOB are zeros, so they are not coded. If one of latter coefficients will be chosen and a non-zero number will be placed in it, a long sequence of zero will be added before this coefficient. The entropy encoder will recognize an irregular situation, which will yield a long code. Obviously, such codes will enlarge the space of an image.

- **The number of bits in each coefficient**

When using more bits in order to accommodate the encrypted message, fewer bits are left for the original value of the coefficient. The quality of the picture can be harmed. A poor quality picture might be suspicious. Someone might suspect that the picture passed some processing. This is exactly what we don't like to occur.

The smuggling algorithm is very simple:

- while there are more bits in the encrypted message
    - read N bits.
    - read one JPEG block into B.
    - decompress B using the entropy decoder.
    - replace N chosen bits from B by N bits from the encrypted message.
    - compress B using the entropy encoder.
    - write block B.

4. Experimental Results

The method was tested on a landscape image, which is shown in Figure 2. The first lines of the image have both a uniform color area and an area, which has sharp changes. This image was chosen, in order to check the sensitivity of the picture to both sorts of data. This image has a 75% quality. This quality is very common in use and it used as a default value in many applications.

Figure 2: Original tested image

The sequence of bits which was inserted into this image is:

1111000011010010011000010111000101011000011110110000000101110111
0111000001101000000111111001111011000011110100000100010100001111111010
1001010110010110101101111101110100110100011101110101010111110000001001
1011100111001000000100101100010010001111110101000111110001000011110010
1010001010100100101101001100010000011000110001110000110001101001000010
0100110001110110100011010101100101011001011000010010111000111101011100
1000100001000000100111010111000000100010001110000010101111010100000001
1100001111010000111011000010001010001111011000000110011010111100111110
1011000011100100100000000100101100100110000000010111001000110000010111 1
1010110100100100000011100011110001000111001011101000100011000000111010
0100101101011101011000110111011111011010101010100011101110000001110001
0010100000011100101110110010001000000110111010010100011000000110001101 0
011001101001010100001111 01

Figure 3: changing one bit in various coefficients

The pictures in Figure 3, were created by insert just one bit into the:

- first AC coefficient
- 21th coefficient
- 41th coefficient
- 61th coefficient

in each JPEG block.

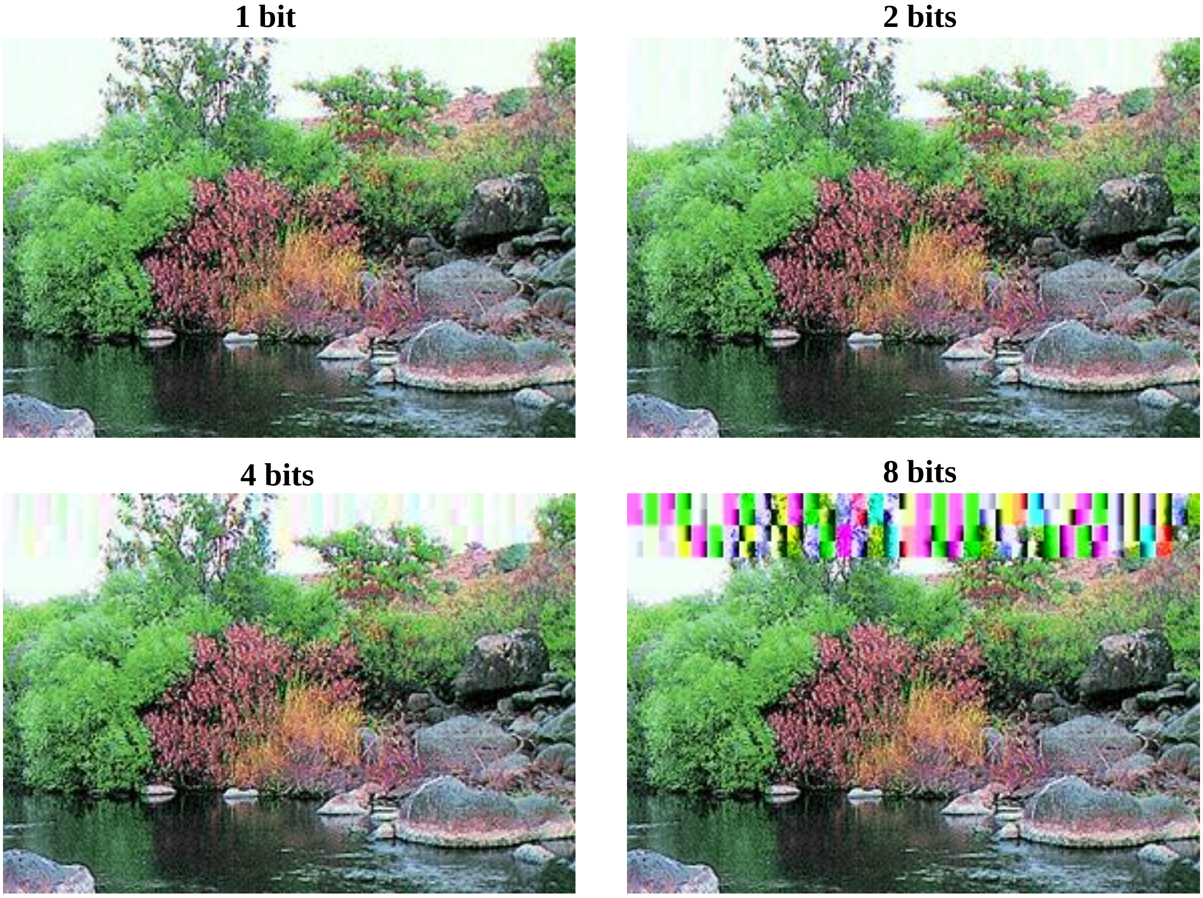

Figure 4: changing several bits in first AC coefficient

When trying to change more than one coefficient, this image will loose a significant data. Someone who sees the last two pictures in Figure 4, can notice that they passed a sort of a treatment. The uniform data is usually more affected. When there are a lot of details, it is hard to notice if something was added or was deleted. When the data is uniform, every addition or deletion is more noticeable. Figures 4 shows changing of 1, 2, 4 and 8 bits in the first AC coefficient.

In order to increase the ability of putting more bits in coefficients, the quality of a picture can be increased. Such an increase gives more bits to each coefficient. Most of these bits are redundant, so changing them might be negligible. Figure 5 shows same picture as was shown in Figure 4, created with a 90% quality. Again, some bits were replaced in the first AC coefficients in the picture. The disadvantage of using high quality image is a larger size of the picture.

Figure 5: changing several bits in the first AC coefficient in a 90% quality image

Sizes of compressed images were affected by number of non-zero values that were compressed. When we insert more bits, the chance to have a non-zero value is growing. In addition, small numbers are handled more efficiently by the compression method implemented in JPEG.

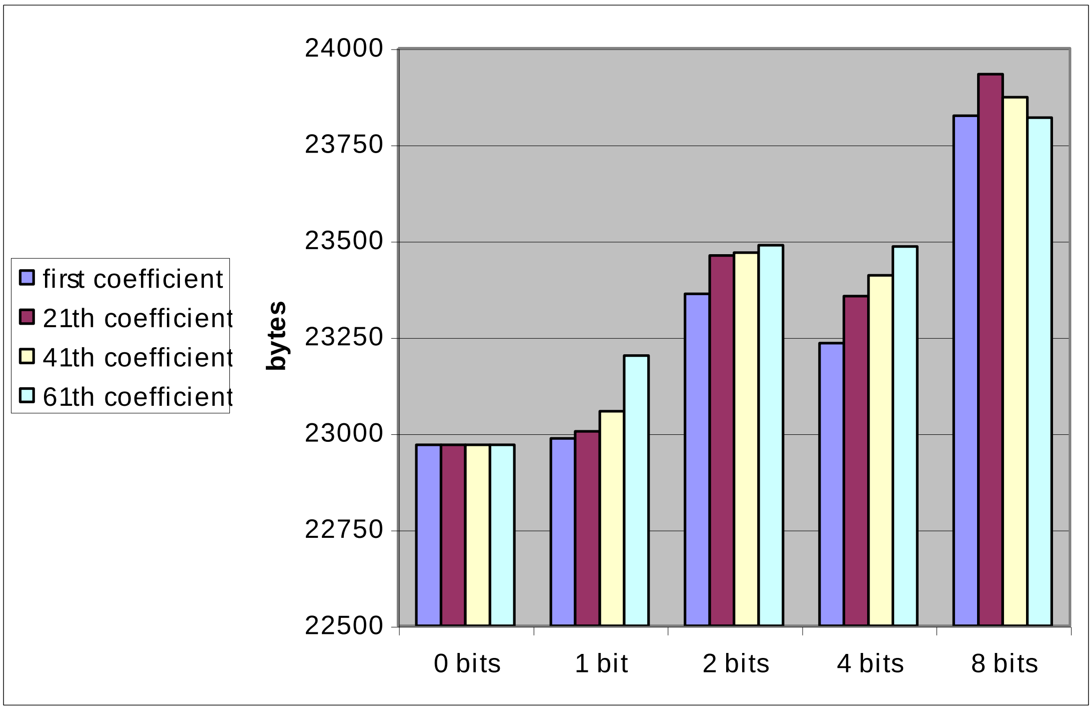

Figure 6: Size of compressed image when some bits were changed

We can see in Figure 6 that when a latter coefficient is changed, the size of the compressed data is larger. Usually, when there is a non-zero value in a latter coefficient, a long sequence of zeros will be before it. A long sequence of zero before a non-zero value is a very rare case, so the entropy encoder will yield for this data, a long sequence of bits. This will increase the size of the compressed image.

The size of a high quality image will be even larger, because JPEG saves more data for each coefficient. The sizes of the images in Figure 5 are 36970 (4 bits) and 37105 (8 bits). The size of the original image with 90% quality is 36940.

5. Conclusions

The experiments have yielded positive results that suggest the proposed technique has potential. JPEG takes off part of the image data, which seems to be redundant. It seems that more data can be removed; yet it will be hard to notice it. This redundant data can be exploited in order to transfer confidential messages.

A further research could be done on what else can be done with the redundant information in JPEG images.

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