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Hiding Data in Images by Digital Watermarking

Field of the invention

The present invention relates to methods and apparatus for data hiding in images, that is for modifying image data to hide data in it.

5 Background of Invention

With the explosion of use and distribution of images and audiovisual digital multimedia content, more and more applications have adopted digital multimedia contents transmission. Examples are Digital TV broadcasting,
10 CD/VCD/DVD storage and internet multimedia streams. On the other hand, traditional analog multimedia broadcasting is still widely used in analog TV broadcasting and radio broadcasting.

It would be valuable to link some additional information to this multimedia
15 content data, in particular information of relevance to the content and which can provide additional services other than in the traditional ways. For example, the linked information could be the TV program listing corresponding to a broadcast program. In another example, lyrics on actor information could be linked to CD or VCD signals, for retrieval while playing the signals.
20 However, conventionally the transmission channels for both digital and analog multimedia contents are normally fixed, and no additional channels are available for the extra information.

Data hiding is a technique for inserting information invisibly into digital content
25 data such as digital audio, image and video data. It does not affect the normal use of the digital content data. Data hiding is an example of digital watermarking. In fact, there are three main types of application for digital watermarking techniques, known respectively as copyright protection,



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contents authentication and data hiding. Copyright protection requires the insertion of "strong" watermark bits, which are able to survive common image manipulations such as compression, geometric distortion and noise attack. By contrast, digital contents authentication requires insertion of a sensitive watermark that would be modified detectably by any alternation to the digital content data after the watermark is embedded. Data hiding requires a watermark that can tolerate distortion in the transmission path, so that it can be recovered.

Some watermarking techniques already exist for data hiding. Certain techniques encode an image as points and divide the image points into two groups using two series of pseudo-random numbers. The data can be hidden by increasing the values of first group of points and decreasing the values of the second group of points. In other techniques image data is hidden in a larger carrier image by encoding the each pixel of the first image as a base 4 representation, and embedding each representation into a corresponding pixel value in the carrier image. In another method message data is hidden by generating media data as a media array, in which the values of certain elements are specified by the values of respective elements of a message to be hidden.

Unfortunately, when the above techniques above are applied to practical situations in which data is to be hidden, the techniques have one or more of the following limitations:

- (1) Sensitivity to possible noise in the transmission channel; thus, if any noise is added in the multimedia data, the hidden data will be lost partly or completely;
- (2) Lack of applicability to all formats of multimedia data; there are lots of multimedia data formats in which the data is conventionally stored and

transferred, such as analog or digital formats, and compressed and uncompressed formats;

(3) High computational load and high system complexity; in some applications, the system has limited resources for the data hiding and recovery process; and

(4) Visible distortions to the original multimedia data; to permit high image quality in the transmitted multimedia data there should be no distortion which can be recognized by human eyes.

10 US 6,738,493 shows a watermarking technique in which an image is divided into blocks, each block is DCT transformed, and the image is modified by quantizing the sum of all the DCT values within the block.

Summary of the Invention

15 The present invention aims to provide new and useful techniques and apparatus for embedding data into content data.

In general terms, the present invention proposes that, for an image in the DCT domain, a plurality of DCT coefficients are selected, and data is embedded
20 into those DCT coefficients by a quantization process.

The DCT coefficients are selected by dividing the images into blocks (e.g. such as the 8x8 blocks which are used in many image compression techniques) and associating blocks into groups by a random process. Then,
25 for each group of blocks, the same DCT coefficients are selected within the blocks of that group.

Since there is a selection of DCT coefficients within the groups, not all the DCT coefficients of the groups are modified. For this reason, embodiments of

the present invention may give rise to a lower level of distortion than, for example, in techniques such as US 6,738,493.

5 The association of the blocks into groups may be done by defining subsections of the image, each sub-section being composed of the same number of complete blocks. For each of the sub-sections, a random order of the blocks is defined. Then each group is defined the blocks in the different sub-sections which correspond to each other under this order.

10 A key may be used to generate values which are used for selecting the order of blocks within the subsections of the image. This key may be kept as secret information, making it much harder for a third party who is not aware of the key to determine what data has been hidden, or even that data has been hidden at all. This provides a degree of security over, for example, the
15 technique of US 6,738,493.

In the quantization process, for each bit of the data to be stored, one or more of the selected DCT coefficients are modified to a quantization value indicative of the bit data to be stored. Or else, for each bit of the data to be
20 stored, each of a set of multiple selected DCT coefficients are modified, such that the sum of the DCT coefficients of the set is equal to a quantization value indicative of the bit of the data to be stored.

In the case that a data bit is to be embedded in a single DCT coefficient, this
25 may be done by, according to the value of that data bit, modifying the DCT coefficient to its nearest value in either a first set of coefficient modification values, or a second set of coefficient modification values.

In the case that a data bit is to be embedded in a set of multiple DCT
30 coefficients, this may be done by, according to the value of that data bit,

modifying the DCT coefficients of the set so that a sum of the DCT coefficients is modified to its nearest value in either a first set of sum modification values, or a second set of sum modification values.

- 5 The embedded data can be recovered from a image which has been watermarked in this way by extracting the DCT coefficients corresponding in location to the selected DCT coefficients, and observing the relationship of those DCT coefficients to the quantization values.
- 10 Certain embodiments of the present invention have one or more of the following advantages, compared with other data hiding methods. Firstly, they cause relatively low distortion to the original multimedia contents. Secondly, they are robust to noise attack. Thirdly, the data embedding and detecting processes are computational simple. Fourthly, if the manner in which the DCT
- 15 coefficients is selected is kept hidden (for example, if it is done based on secret keys), then the embedded data is relatively secure against attack by a third party who does not know the keys.

Embodiments of the invention can be used for both analog and digital

20 multimedia content data. Typically, embodiments which operate on analog content data include an initial analogue-to-digital conversion step before the data embedding step. The data embedding step is typically followed by a digital-to-analogue conversion to retrieve watermarked analog content data.

25 Furthermore, embodiments of the invention can be used for both compressed and uncompressed multimedia contents. Typically, embodiments which operate on compressed content data include an initial decompression step before the data embedding step. The data embedding step is typically followed by a compression step to retrieve watermarked compressed data.

Furthermore, embodiments of the invention can be used for images which are frames of a video sequence, such as in analog, MPEG-1,2 and 4, and H.264 signals, etc.

- 5 As mentioned above, optionally multiple DCT coefficients may be used to embed the same data bit. The sets of multiple coefficients used for embedding a given data bit may be coefficients from different associated blocks.
- 10 Furthermore, the selection of which DCT coefficients are used for embedding may depend upon the value of those coefficients. Only DCT coefficients may be used which fall into predefined ranges (dependent upon the type of image). For example, experimentally, it has been found that, for analog and raw images, performing embedding using only DCT coefficients in the range
15 40~48 (where the DCT value is an integer in the range 0 to 255) increases the image quality and robustness to noise attack. Conversely, for high compressed images, it has been found that selecting DCT coefficients which take the value 5, 6, 9 and 10 tends to maintain the image quality.
- 20 Optionally, in this case, the changes made to the DCT coefficients of the set are not all the same. Rather, different ones of the DCT coefficients in the set may be changed by different respective amounts, which are lower for DCT coefficients of relatively lower values.
- 25 Optionally, the coefficient modification values (or alternatively sum modification values) may be predefined. Alternatively, they may be derived in a preliminary step of the method based on a statistical analysis of the image. For example, a set of DCT coefficients can be selected from the image and

used to define a scaling factor for setting the coefficient/sum modification sets. In this way, the modification sets may be chosen to reduce the distortion to the image caused by the embedding. In particular, by this technique of using adaptive modification sets, the data hiding scheme can be more robust to image contrast and brightness change and keep the image quality better.

Brief Description of The Figures

Preferred features of the invention will now be described, for the sake of illustration only, with reference to the following figures in which:

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Fig. 1 is the basic scheme for embedding data in analog images in an embodiment of the invention;

Fig. 2, which is composed of Fig. 2(a) and 2(b), shows two examples of dividing an image into 3 subsections in the embodiment of Fig. 1;

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Fig. 3 shows a process to select and modify DCT coefficients in the embodiment of Fig. 1;

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Fig. 4 illustrates how different parts of a DC block with 8×8 DCT coefficients are used for AC Summing and Data Hiding in a third embodiment of the invention;

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Fig. 5 is composed of Fig. 5(a) and 5(b), which show respectively the data embedding and detected processes of the third embodiment of the invention;

Fig. 6 illustrates schematically the adaptation of coefficient values in the third embodiment of the invention; and

Fig. 7 is the flow diagram of a fourth embodiment of the invention, employing a compressed image file.

5 Detailed Description of the embodiments

An embodiment of the invention employing analog images will now be described in detail. Subsequently, extensions of the embodiment to other formats are described.

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The basic scheme of the embodiment is shown schematically in Fig. 1. The starting point of the method is an analog host image 1. The host image 1 can be either a greyscale or a colour image. Greyscale images will be used here to describe the embodiments. Note that this is without loss of generality, since
 15 colour images in digital formats such as ***RGB, YCbCr, etc.*** can be converted for example into the ***YIQ*** format, where the luminance component ***Y*** of ***YIQ*** represents image brightness and therefore can be treated as a greyscale image.

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The analog host image 1 is firstly converted into digital format 2 by an AD conversion circuit. For example, an analog pixel would take a value in the range of 0 to 255 after it is operated on by an 8-bit AD converter. The converted digital image 2 should be of the same size as the original analog image 1 in terms of the number of pixels. Let us denote this size as
 25 $A \times B$ pixels.

After the AD conversion, the converted image 2 is divided into small blocks. Each block contains the same number of pixels H_1 in the height direction, and each block contains the same number of pixels L_1 in the length direction.

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Thus each block is $H_1 \times L_1$ pixels (typically 8×8 pixels). Hence, the image is

divided into $K = (A/H_1) \times (B/L_1)$ blocks. K is typically at least about 100, and can be much higher. A 2-dimensional DCT transform is then applied to every such block, so that the pixel values of each block are transformed to $H_1 \times L_1$ DCT coefficients 3.

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The next step is to embed data in the DCT coefficients, to give modified data 4. This is done as follows.

Firstly, using the K blocks, the image frame is divided into n non-overlapping
10 subsections. Each of the subsections contains the same number of complete blocks $k = K/n$. These n subsections can be obtained in any convenient manner. Two examples are given in Figs. 2(a) and 2(b), respectively in the case that $n = 3$, the three subsections being three vertical slices in the case of Fig. 2(a), and three horizontal slices in the case of Fig. 2(b). For each of these
15 two ways of partitioning the image, the three slices contain the same number of pixels. Alternatively, the subsections can be obtained by a random process, for example, as in the following manner:

- 1) Choose a subsection of k blocks randomly from all the K blocks,
- 2) Choose another set of k blocks randomly from all the remaining $(K - k)$
20 blocks, and
- 3) Repeat process 2) until all n subsections are selected.

In each subsection, the blocks are put in a random sequence by some random permutation function using a secret key. Specifically, in subsection i ,
25 the k blocks are randomly ranked using random values $\{b_1, \dots, b_k\}$ generated using a predefined algorithm and the secret key. This sequence is denoted (in an obvious notation) by $S_{i_b_1}, S_{i_b_2}, \dots, S_{i_b_k}$.

The blocks in the corresponding positions of these sequences are then associated, thereby forming k groups, each group being composed of n blocks. The j^{th} group of blocks is thus composed of blocks $S_1_b_j, S_2_b_j, \dots, S_n_b_j$.

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For each group of blocks, and for each block within the group, a set of t coefficients is selected. We will denote the coefficients selected from the j^{th} group of as C_{jp}^i where i is a dummy index running from 1 to n and representing the different sub-sections, and p is a dummy index running from 1 to t . This is illustrated in Fig. 3, where for each of blocks 8, $t = 9$ coefficients (labelled by reference numeral 9) are marked. This process can be denoted as:

$$\begin{aligned}
 S_1_b_j : & \quad C_{j1}^1, C_{j2}^1, C_{j3}^1, \dots, C_{jt}^1 \\
 S_2_b_j : & \quad C_{j1}^2, C_{j2}^2, C_{j3}^2, \dots, C_{jt}^2 \\
 & \quad \dots \\
 S_i_b_j : & \quad C_{j1}^i, C_{j2}^i, C_{j3}^i, \dots, C_{jt}^i \\
 & \quad \dots \\
 S_n_b_j : & \quad C_{j1}^n, C_{j2}^n, C_{j3}^n, \dots, C_{jt}^n
 \end{aligned} \tag{1}$$

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Thus, for each group of blocks, the DCT coefficients identified by Eqn. (1) form a group of nt DCT coefficients.

In the next stage, one or more bits of data are embedded into the selected DC coefficients. A given data bit may be embedded into just one of the selected DCT coefficients. Alternatively, a given data bit may be embedded in more than one (or even all) of the group of nt DCT coefficients, to enhance robustness.

20

A possible method for embedding data into all the DCT coefficients in the group can be stated as follows: depending upon whether a given data bit to be embedded is 1 or 0, each DCT coefficient is modified by either Strategy 1 or 2 (to be described below). That is, if the given data bit is 1, each associated DCT coefficient in the group will be modified according to Strategy 1. Otherwise, it will be modified according to Strategy 2.

For Strategy 1, a set of real numbers is defined as $\{..., P_i, P_{i+1}, ...\}$. For Strategy 2, another set of real numbers is defined as $\{..., Q_i, Q_{i+1}, ...\}$. Values in these two sets are different from one another (i.e. $P_i \neq Q_j$ for any pair of i and j) and one of the sets of real numbers is generally interlaced with the other (refer to the example below). These two sets of real numbers are referred to here as the "coefficient modification sets" for convenience. In strategy 1, the set of identified DCT coefficients is modified by changing each coefficient value to its nearest respective value within the coefficient modification set $\{..., P_i, P_{i+1}, ...\}$. Similarly, in strategy 2, the set of identified DCT coefficients is modified by changing each coefficient value to its nearest respective value within the coefficient modification set $\{..., Q_i, Q_{i+1}, ...\}$.

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For example, suppose that for Strategy 1 the coefficient modification set is $\{..., -12, -6, 0, 6, 12, ...\}$, and that for Strategy 2 the coefficient modification set is $\{..., -9, -3, 3, 9, 15, ...\}$. If $C_{jp}^n = 8.2$ for a certain value of p in block $S_n - b_j$, and if the data bit to be embedded is 1, then it will be modified to 6 by Strategy 1. Conversely, if the data bit is 0, C_{jp}^n will be modified to 9 by Strategy 2.

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The elements in the two coefficient modification sets can be any real numbers, subject to only one basic requirement that the values in one set

should be different from those in the other set. The larger the distance between the nearest pair of real numbers in each set, the more robust the method tends to get against noise. Conversely, however, the larger the distance between the nearest pair of real numbers in each set, the more visible distortion tends to appear in the host data. A well-selected set of real numbers should provide a good balance between these two conflicting tendencies.

After data is embedded, the modified DCT coefficients are transformed back to blocks of image pixel values, and then converted back to analog format data by a DA converter. The image can then be transmitted to a user.

In detecting the hidden data, the same procedure as described above in the embedding process will be employed to identify the DCT coefficients which were modified during the embedding process. Since the DCT coefficients are prone to change due to some possible signal distortions during data transmission and the DA/AD process, $\hat{C}$ is used to denote the DCT coefficient altered as such:

$$\begin{aligned}
 S_1 - b_j : & \quad \hat{C}_{j1}^1, \hat{C}_{j2}^1, \hat{C}_{j3}^1, \dots, \hat{C}_{jp}^1 \\
 S_2 - b_j : & \quad \hat{C}_{j1}^2, \hat{C}_{j2}^2, \hat{C}_{j3}^2, \dots, \hat{C}_{jt}^2 \\
 & \dots \\
 S_i - b_j : & \quad \hat{C}_{j1}^i, \hat{C}_{j2}^i, \hat{C}_{j3}^i, \dots, \hat{C}_{jt}^i \\
 & \dots \\
 S_n - b_j : & \quad \hat{C}_{j1}^n, \hat{C}_{j2}^n, \hat{C}_{j3}^n, \dots, \hat{C}_{jt}^n
 \end{aligned} \tag{2}$$

The modified DCT coefficients $\hat{C}_{jp}^i$ are each checked using both Strategies 1 and 2. If a given DCT coefficient is closer to some value in the coefficient

modification set $\{..., P_i, P_{i+1}, ...\}$ for Strategy 1, data bit 1 will be detected; otherwise, data bit 0 is detected. For instance, using the two coefficient modification sets illustrated above, if $\hat{C}_{jp}^i = 8.8$, the data bit is judged to be bit 0, whereas, if $\hat{C}_{jp}^i = 5.8$, the data bit is judged to be bit 1.

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One way to make the method more robust against noise attack is to embed the same data bit into more than one of the DCT coefficients in Eqn. (1), or even all the coefficients. In this way, the data bit can be repeatedly checked and the final decision will be made by counting both the number of coefficient
10 values which suggest that the embedded bit 1 and the number of coefficients which suggest that the embedded bit was 0. If there happen to be more coefficients indicating that the embedded bit was 1, the data bit will be finally judged to be bit 1; otherwise, it is judged to be 0.

15 Another way to make the method more robust against noise attacks is to increase the distance between two adjacent real numbers in each coefficient modification set, thus decreasing the probability of erroneous decision.

In order to increase the robustness, it is also effective to select an optimal
20 range of DCT coefficients within a block for embedding. One embodiment can be given as follows: considering the block size of 8×8 , the range of DCT coefficients can be selected from 40 through 48 (note that the DCT coefficients are typically ordered for coding/decoding by the so-called zigzag scan in the order of low to high frequency from the top-left corner of a given
25 block, i.e. from 1 to 64). In this case we have found that it is effective if the distances between the nearest pair of real numbers in each coefficient modification set is 6 or 7. These DCT coefficients and distance values are found to be quite effective in establishing a good balance between image quality and robustness against noise.

We now turn to a second embodiment of the invention. Instead of modifying individual selected DCT coefficients in the same group, the second embodiment is a variant in which the summed value of the selected DCT coefficients in the group is modified. As in the above case, the whole image contains $k = K/n$ groups of DCT coefficients. The summed value for the selected group of DCT coefficients in Eq.(1) is:

$$C_SUM_j = \sum_{p=1}^t \sum_{i=1}^n C_{jp}^i \quad j=1,2,\dots,k$$

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If the j^{th} data bit is 1, C_SUM_j will be modified by using Strategy A. On the other hand, if it is 0, C_SUM_j will be modified by using Strategy B.

For Strategy A, a set of real numbers is defined as $\{..., PP_i, PP_{i+1}, ...\}$. For Strategy B, another set of real numbers is defined as $\{..., QQ_i, QQ_{i+1}, ...\}$. Values in these two sets need to be different from one another, namely $PP_i \neq QQ_j$ for any pair of i and j and one set will generally be interlaced with the other set. We call these two sets of real numbers the sum modification sets for convenience. In either case, C_SUM_j will be modified to its nearest value within the set.

ΔC_SUM_j , defined as the difference between C_SUM_j and the nearest value to it in the sum modification set corresponding to the data bit to be encoded. ΔC_SUM_j is distributed among the DCT coefficients in the group (optionally it can be distributed equally, but as described below preferably it is not). Comparing this process with the modification process described above, we

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find the modification done to C_SUM_j to be much larger owing to the summation operation. This certainly makes the method more robust.

In one form of the embodiment, the modification to each single DCT coefficient ΔC_{jp}^i is given by the ratio of its absolute original value to the sum of the absolute values of all the DCT coefficients in the group, namely

$$\Delta C_{jp}^i = \Delta C_SUM_j \times |C_{jp}^i| / C_ABS_SUM_j,$$

in which $C_ABS_SUM_j$ represents the sum of all the absolute values of the DCT coefficients in the j^{th} group, as given by

$$C_ABS_SUM_j = \sum_{i=1}^n \sum_{p=1}^t |C_{jp}^i|.$$

Note that compared to distributing ΔC_SUM_j equally over the DCT coefficients of the group, this method of weighting the distribution of ΔC_SUM_j over each DCT coefficient in the group should work better in terms of image quality after embedding because the weighting factor for each DCT coefficient in the group is determined by the ratio of its absolute original magnitude to the sum of the absolute magnitudes of all the DCT coefficients in the group.

Just as in the first embodiment, after data is embedded, the modified DCT coefficients are transformed back to the blocks of image pixel values, and further back to the analog format through a DA converter.

During detection, the same blocks of DCT coefficients will be grouped in the same way as for the embedding process. The summed value of the DCT coefficients $C_SUM'_j$ will be checked by using both Strategies A and B. If $C_SUM'_j$ is closer to some value in the sum modification set for Strategy A, data bit 1 will be detected; otherwise, data bit 0 is detected.

By using the summed value $C_SUM'_j$ of the DCT coefficients, the embedded data can be made more robust against distortion in the transmission channel, the reason being that part of the noise effect is more likely to be cancelled in the statistical sense by summing the DCT coefficients since distortions are expected to result in a combination of plus and minus changes to the DCT coefficients. Another merit of this method lies in the fact that a single detection will permit one bit to be detected, unlike the first embodiment in which multiple comparisons with the coefficient modification set are required.

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We turn now to a third embodiment of the present invention, which provides a means to choose the values of the two modification sets (i.e., the coefficient modification set and the sum modification set), adaptively to a given image. In the third embodiment, a plurality of the DCT coefficients 10 are selected in addition to the DCT coefficients 9 selected for data hiding, as shown in Figure 4. A block 8 with 8×8 DCT coefficients is shown in Figure 4 where the DCT coefficients 10 and the DCT coefficients 9 are shown by different grey levels. The DCT coefficients 10 are selected in order to obtain a scaling factor to adapt the values of the two modification sets to the image before and after data transmission, and the DCT coefficients 9 are modified as in the first method for data hiding using the adapted modification sets. For this adaptive process, which is described below in detail, the DC coefficient (i.e. the first DCT coefficient in the top-left corner of the block) is not used because of the property of the DC coefficient that it represents the average of all the pixel

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values in the corresponding block and changes with image brightness, thus making it not suitable for either method. Furthermore, by not including the DC coefficient, the data hiding scheme of the present embodiments is made robust to changes in the overall image brightness.

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The steps of the method of the third embodiment are shown in Fig. 5(a) for the embedding process, and Fig. 5(b) for the recovery process.

The first two steps of the embedding process are the same as for the first and second embodiment: AD conversion (step 11) and DCT transform (step 12). Then, in step 13, for all the blocks in this image, we add up the absolute values of the selected DCT coefficients 10, to derive the value of $SUM_ABS_AC_{embed}$. Note that the coefficients 9 (the ones to be used for data hiding) will not be added in. The DCT coefficients 10 can be selected in any manner, and need not be the same for different blocks, but DCT coefficients of relatively low frequency are recommended for better robustness against image contrast changes.

Step 13 can also be expressed as summing up the selected DCT coefficients 10 in all $K = (A/H_1) \times (B/L_1)$ blocks in the image with a pixel size of $A \times B$ and block size $H_1 \times L_1$. If $C_{s1}, C_{s2}, C_{s3} \dots C_{sm}$ (where m is the number of coefficients 10 per block) are the selected DCT coefficients 10 for block S_k , the sum of the absolute values of all the selected AC coefficients will be given by

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$$SUM_ABS_AC_{embed} = \sum_{k=1}^K \sum_{b=1}^m C_{sb}$$

In step 14, $SUM_ABS_AC_{embed}$ is compared with a pre-defined value, which is referred to here as $SUM_Measure$. This value is pre-defined, based on a selected balance between achieving high robustness and high image quality. A good choice can be determined by trial and error, based on typical images in the context. Preferably, the value is normalised based on the number of DCT coefficients 10. Step 14 results in two adapted coefficient modification sets:

$$P'_i = P_i \times SUM_ABS_AC_{embed} / SUM_Measure$$

$$Q'_j = Q_j \times SUM_ABS_AC_{embed} / SUM_Measure$$

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or else two adapted sum modification sets

$$PP'_i = PP_i \times SUM_ABS_AC_{embed} / SUM_Measure$$

$$QQ'_j = QQ_j \times SUM_ABS_AC_{embed} / SUM_Measure$$

15 Data will be hidden in step 15 by using either of the methods explained above in relation to the first and second embodiments of the invention, respectively using adapted modification sets $\{..., P'_i, P'_{i+1}, ...\}$ and $\{..., Q'_i, Q'_{i+1}, ...\}$ for Strategies 1&2, or $\{..., PP'_i, PP'_{i+1}, ...\}$ and $\{..., QQ'_i, QQ'_{i+1}, ...\}$ for Strategies A&B. The DCT coefficients 9 for data hiding will be selected excluding the DC coefficient and
20 the AC DCT coefficients 10.

The detection process is shown in Fig. 5(b). The first two steps are the same as in the first and second embodiments: an AD conversion (step 21) and a DCT transform (step 22). Then, in step 23, for all the blocks in this image, we
25 add up the absolute values of the selected DCT coefficients 10 in the same

way as for the embedding process, to re-obtain the value of $SUM_ABS_AC_{detect}$.

$$SUM_ABS_AC_{detect} = \sum_{k=1}^K \sum_{b=1}^m \hat{C}_{sb}, \text{ where } \hat{C}_{sb} \text{ are the values of the DCT}$$

5 coefficients 10 in the image from which the watermark is to be extracted.

In step 24, $SUM_ABS_AC_{detect}$ will be compared with the pre-defined measurement $SUM_Measure$ to re-obtain the adapted modification sets:

$$10 \quad P_i'' = P_i \times SUM_ABS_AC_{detect} / SUM_Measure$$

$$Q_j'' = Q_j \times SUM_ABS_AC_{detect} / SUM_Measure$$

or

$$PP_i'' = PP_i \times SUM_ABS_AC_{detect} / SUM_Measure$$

$$QQ_j'' = QQ_j \times SUM_ABS_AC_{detect} / SUM_Measure$$

15 In step 25, the data is detected by using either method treated above with its corresponding adaptive modification sets $\{..., P_i'', P_{i+1}'', ...\}$ and $\{..., Q_i'', Q_{i+1}'', ...\}$ for Strategies 1 and 2 (or $\{..., PP_i'', PP_{i+1}'', ...\}$ and $\{..., QQ_i'', QQ_{i+1}'', ...\}$ for Strategies A and B).

20 The first and second embodiments have flow diagrams for encoding and detecting which are respectively like Fig. 5(a) and Fig. 5(b), except that steps 13, 14 and 23, 24 are omitted.

Figure 6 schematically depicts the adaptive process. The "original axis" 31 has predefined modification sets for Strategies 1 and 2 (or Strategies A and 25 B) indicated by circles and crosses. The distance between any adjacent pair

of values in the initial modification sets is ΔD . $SUM_Measure$ is also defined as a reference value.

In the embedding stage, $SUM_ABS_AC_{embed}$ for the host image is generally different from $SUM_Measure$ and its ratio relative to $SUM_Measure$ is given by $k1 = SUM_ABS_AC_{embed} / SUM_Measure$. The values on the original axis 31 are changed to those on the "embedding axis" 32 on the left of the figure by a factor of $k1$. The distance between a circle and its adjacent cross is now $k1 \cdot \Delta D$. Data will be hidden into the host image by using the values on the embedding axis.

In the detection stage, $SUM_ABS_AC_{detect}$ is generally different from $SUM_ABS_AC_{embed}$ due to contrast changes that could occur during data transmission and its ratio relative to the $SUM_Measure$ is given by $k2 = SUM_ABS_AC_{detect} / SUM_Measure$. The values on the original axis are changed to those on the "detecting axis" 33 on the right of the figure by a factor of $k2$. The distance between a circle and its adjacent cross is now $k2 \cdot \Delta D$. The data can still be detected by using the values on the detecting axis. Contrast change to the image will result in the changes of the DCT coefficients by a scaling factor of $SUM_ABS_AC_{detect} / SUM_ABS_AC_{embed} = k2 / k1$. The ratio of change in distance between the detecting and embedding axes is also $k2 \cdot \Delta D / (k1 \cdot \Delta D) = k2 / k1$. In this way, distortion effects due to contrast change can be removed.

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Advantages to be gained from the adaptive scaling of the initial values in the modification sets based on AC DCT coefficients are as follows:

1. The data hiding scheme is robust to image brightness changes because the DC coefficient is not involved in the modification process at all.
- 5 2. The data hiding scheme can keep the image quality better by adopting the above-described technique of adaptively scaling the values in the modification sets. Images with small DCT coefficients will get only a small modification and hence visual distortion will be reduced. For an image with big DCT coefficients, although it will suffer a large modification, the modification is still small relative to the original DCT
10 coefficients and hence the image will still keep good quality with better robustness. On the other hand, for an image with very small DCT coefficients, the modification to these coefficients will also be very small. Although the image quality is still kept well, the embedded data may lose its robustness against a particular attack.
- 15 3. The data hiding scheme can be made robust against image contrast changes by making the modification adaptive to the image itself. The reason is that image contrast changes will cause all the AC coefficients to change accordingly. By making the quantization values adaptive for detection, this method can well survive the distortion due to contrast
20 change.

The three embodiments described above can be modified straightforwardly to other formats of multimedia data. For those formats that are not related to JPEG, the data is first transformed back to the raw image and then divided
25 into blocks. Generally, this data will be digital, so the process is performed on the blocks exactly as described above in relation to the embodiments except that the steps of AD and DA conversion are omitted.

For JPEG related multimedia data like JPEG image, MPEG-1, -2 and -4, and H.264, the process becomes much simpler. For the other JPEG related video, each frame or error prediction blocks can be regarded as a single JPEG file.

5 Figure 7 shows a fourth embodiment of the invention, which is a process for data hiding in JPEG files. In the JPEG compression scheme, the image is first divided into many blocks and the 2-D DCT is performed within each block, followed by the standard quantization of the DCT coefficients. The quantized DCT coefficients are then put in a one-dimensional vector by the so-called
10 zigzag scan, followed by the run-length coding and entropy coding (Huffman coding) to obtain the JPEG image file. To hide data into a JPEG image, the modification should be performed on the quantized DCT coefficients. Otherwise, the quantization process will erase the modification effects, thereby losing the hidden data.

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The data hiding scheme for JPEG images shown in Figure 7 it is assumed that the quantized DCT coefficients should be modified to embed data. The JPEG image file are first converted into the quantized DCT coefficients by inverse Huffman coding (step 41). After that, a procedure similar to the one
20 used in the first three embodiments of the invention is adopted: a random grouping of blocks followed by a selection of the DCT coefficients to be used for encoding (step 42, which is identical to the corresponding steps of the first three embodiments), and then an encoding step 43. In step 43 a data bit is hidden by selecting and modifying some DCT coefficients by the two
25 coefficient modification sets. Huffman coding is then executed on the modified quantized DCT coefficients (step 44) to get the watermarked JPEG image file.

However, due to the quantization step in JPEG compression, small changes in quantized DCT coefficients will lead to large changes to the real DCT
30 coefficients. Hence the JPEG image will be distorted quite a lot especially for

those highly compressed JPEG image files. To keep the image quality, it is preferable in step 43 to make the distance between the nearest pair of values in each modification set small. Since the quantized DCT coefficients are integers, the distance between the nearest pair of values in each modification
5 set should be 1 and therefore the modification to the quantized DCT coefficients can only be either +1 or -1. This +1 or -1 modification imparts a relatively small change to the DCT coefficients, thus making the watermark less visible.

10 When the JPEG compression ratio becomes larger, making the distance 1 between the nearest pair of values in each modification set is not enough to keep the image quality to. By selecting the proper quantized DCT coefficients, the image quality can be even better for those modified JPEG files. One example is to select the quantized DCT coefficients to be one of 5, 6, 9 and
15 10 to keep the image quality better. It is also found that limiting the quantized DCT coefficients to 6 and 9 can further enhance the image quality.

The above procedure can be readily extended to JPEG related digital video files by simply setting the embedding target to video contents (blocks of DCT
20 coefficients).

More generally, although only a few embodiments of the invention have been described above in detail, many variations are possible within the scope of the invention as will be apparent to a skilled reader.

Claims

1. A method of embedding data in a set of image data to form watermarked image data, the method including the steps of:
 - obtaining the image data in the form of DCT coefficients in blocks, each
 - 5 block of DCT coefficients representing a DCT transform of a corresponding block of the image;
 - associating the blocks into groups by a random process; and
 - for each group of blocks, selecting one or more DCT coefficients from
 - 10 within each block of the group, the selected DCT coefficients for different blocks of the group being at corresponding locations within the blocks;
 - for each bit of the data to be embedded quantizing each of a corresponding set of one or more of the selected DCT coefficients.
- 15 2. A method according to claim 1 in which the quantization is performed by,
 - if the data bit has a first binary value, changing the one or more of the selected DCT coefficients to the closest of a first set of modification values; or
 - if the data bit has the other binary value, changing the one or more of
 - 20 the selected DCT coefficients to the closest of a second set of modification values.
3. A method of embedding data in a set of image data to form watermarked image data, the method including the steps of:
 - 25 obtaining the image data in the form of DCT coefficients in blocks, each block of DCT coefficients representing a DCT transform of a corresponding block of the image;
 - associating the blocks into groups by a random process; and

for each group of blocks, selecting one or more DCT coefficients from within each block of the group, the selected DCT coefficients for different blocks of the group being at corresponding locations within the blocks;

for each bit of the data to be embedded quantizing the sum of a
5 corresponding plurality of the selected DCT coefficients.

4 A method according to claim 3 in which the quantisation is performed by:

10 if the data bit has a first binary value, changing the plurality of the selected DCT coefficients to make their sum the closest of a first set of modification values; or

if the data bit has the other binary value, changing the plurality of the selected DCT coefficients to make their sum the closest of a second set of modification values.

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5. A method according to claim 4 in which, in each said step of changing a plurality of the selected DCT coefficients, different ones of the DCT coefficients are changed by different respective amounts, said amount being lower for DCT coefficients of relatively lower values.

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6. A method according to claim 1 or claim 3 in which said step of obtaining image data in the form of DCT coefficients comprises transforming image data in the spatial domain into DCT coefficients by a DCT transform.

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7. A method according to claim 6 including, if the image data in the spatial domain is analogue data, a step prior to said DCT transform of digitising the image data.

8. A method according to any preceding claim including a step, following the modification step, of transforming the DCT coefficients into the spatial domain.
- 5 9. A method according to claim 8 including a further step, following said step of transforming the DCT coefficients into the spatial domain, of transforming the modified spatial domain data into analogue data.
- 10 10. A method according to any preceding claim in which said step of obtaining image data in the form of DCT coefficients includes a step of decompressing compressed image data.
- 15 11. A method according to claim 10 further including, following said modification step, using the modified DCT coefficients to form compressed image data.
- 20 12. A method according to any preceding claim in which the DCT coefficients are associated into groups by the steps of:
- 25 defining subsections of the image, each composed of the same number of complete blocks;
- for each of the sub-sections, defining an order of the blocks; and
- defining groups of blocks; each group of blocks being blocks in different sub-sections which are in the same respective position according to the defined order.
13. A method according to claim 12 in which the order of the blocks is defined by using a key to generate a random sequence.

14. A method according to any preceding claim in which only DCT coefficients which fall into predetermined ranges are selected.
15. A method according to claim 14 in which the DCT coefficients are in the range 0 to 255, and the selected DCT coefficients are in the range 40 to 48.
16. A method according to any preceding claim including a step of deriving the modification values using the set of image data.
17. A method according to claim 16 in which said step of deriving the modification values includes deriving a scaling factor using the set of image data, and multiplying each of a plurality of predefined values by the scaling factor to derive the modification values.
18. A method according to claim 17, when dependent upon claim 12, in which the scaling factor is derived from DCT coefficients of the image data other than the selected DCT coefficients.
19. A method of recovering embedded data from watermarked image data derived by a watermarking method according to claim 2, the method including:
obtaining the watermarked image data in the form of DCT coefficients;
for each bit of the embedded data:
(i) obtaining the one or more DCT coefficients modified during the watermarking method in accordance with the bit of embedded data; and
(ii) if more than half of the one or more DCT coefficients are closer to one or the first set of modifications values than to any of the second set of modification values, determining that the bit of the embedded data is the first binary value; or

(iii) if more than half of the one or more DCT coefficients are closer to one or the second set of modifications values than to any of the first set of modification values, determining that the bit of the embedded data is the second binary value.

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20. A method of recovering embedded data from watermarked image data derived by a watermarking method according to claim 4, the method including:
obtaining the watermarked image data in the form of DCT coefficients;
for each bit of the embedded data:

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(i) obtaining the set of DCT coefficients modified during the watermarking method in accordance with the bit of embedded data; and

(ii) if the sum of the set of DCT coefficients is closer to one or the first set of modifications values than to any of the second set of modification values, determining that the bit of the embedded data is the first binary value;

15

or

(iii) if the sum of the set of DCT coefficients is closer to one or the second set of modifications values than to any of the first set of modification values, determining that the bit of the embedded data is the second binary value.

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21. An apparatus for embedding data in a set of image data to form watermarked image data, the apparatus including a processor arranged to perform the steps of:

obtaining the image data in the form of DCT coefficients in blocks, each
25 block of DCT coefficients representing a DCT transform of a corresponding block of the image;

associating the blocks into groups by a random process; and

for each group of blocks, selecting one or more DCT coefficients from within each block of the group, the selected DCT coefficients for different
30 blocks of the group being at corresponding locations within the blocks;;

for each bit of the data to be embedded quantizing each of a corresponding set of one or more of the selected DCT coefficients.

22. An apparatus for embedding data in a set of image data to form
5 watermarked image data, the apparatus including a processor arranged to perform the steps of:

obtaining the image data in the form of DCT coefficients in blocks, each block of DCT coefficients representing a DCT transform of a corresponding block of the image;

10 associating the blocks into groups by a random process; and
for each group of blocks, selecting one or more DCT coefficients from within each block of the group, the selected DCT coefficients for different blocks of the group being at corresponding locations within the blocks;

for each bit of the data to be embedded quantizing the sum of a
15 corresponding plurality of the selected DCT coefficients.

23. An apparatus for recovering embedded data from watermarked image data derived by a watermarking method according to claim 2, the apparatus including a processor arranged to perform the steps of:

obtaining the watermarked image data in the form of DCT coefficients;
20 for each bit of the embedded data:

(i) obtaining the one or more DCT coefficients modified during the watermarking method in accordance with the bit of embedded data; and
(ii) if more than half of the one or more DCT coefficients are closer to one or the first set of modifications values than to any of the second set of
25 modification values, determining that the bit of the embedded data is the first binary value; or

(iii) if more than half of the one or more DCT coefficients are closer to one or the second set of modifications values than to any of the first set of

modification values, determining that the bit of the embedded data is the second binary value.

24. An apparatus for recovering embedded data from watermarked image data derived by a watermarking method according to claim 4, the apparatus
- 5 including a processor arranged to perform the steps of:
- obtaining the watermarked image data in the form of DCT coefficients;
 - for each bit of the embedded data:
 - (i) obtaining the set of DCT coefficients modified during the watermarking method in accordance with the bit of embedded data; and
 - 10 (ii) if the sum of the set of DCT coefficients is closer to one or the first set of modifications values than to any of the second set of modification values, determining that the bit of the embedded data is the first binary value; or
 - (iii) if the sum of the set of DCT coefficients is closer to one or the
 - 15 second set of modifications values than to any of the first set of modification values, determining that the bit of the embedded data is the second binary value.