AUTOMATIC GENERATION OF LINE-BASED CUBISM-LIKE ART IMAGES AND THEIR APPLICATION TO DATA HIDING

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ABSTRACT

A new type of computer art, called line-based Cubism-like image, is proposed, which keeps a characteristic of the Cubism art — multiple viewpoints — by the use of line and region features. In the creation process with an input source image, prominent line segments in the image are detected and rearranged to form an abstract region-type art image of the Cubism flavor. In a process of re-coloring the regions in the generated art image, a data hiding technique for covert communication is designed skillfully to embed secret message bits in the pixels' colors by keeping the average region color unchanged. Experimental results show the feasibility of the proposed method.

Keywords: *art image; line-based Cubism-like image; data hiding; cover image; stego-image; secret message.*

1. INTRODUCTION

In recent years, the topic of creating art images via the use of computers arouses interests of many people. Many methods have been proposed to create art images automatically [1]-[9].

Hertzmann [1] surveys many ideas of creating art images by *stroke-based rendering* (SBR), which is defined to be an automatic approach to creating non-photorealistic imagery by placing discrete elements, like paint strokes and stipples, in the resulting image. He also surveyed several SBR algorithms and styles such as painting, pen-and-ink drawing, tile mosaics, and so on. The common goal of creating these image styles is to make generated art images look like some other types of images. For example, two images created by watercolor painting and oil painting in Hertzmann [2] and Hertzmann [3], respectively, are shown in Fig. 1. Some other types of art images are shown in Fig. 2, where Fig. 2(a) is an image created by pen-and-ink illustration proposed by Salisbury [4], Fig. 2(b) is a stipple image created by a stipple placement method proposed by Mould [5], and Fig. 2(c) shows a stain-glass image created by an image filtering scheme presented in Mould [6].

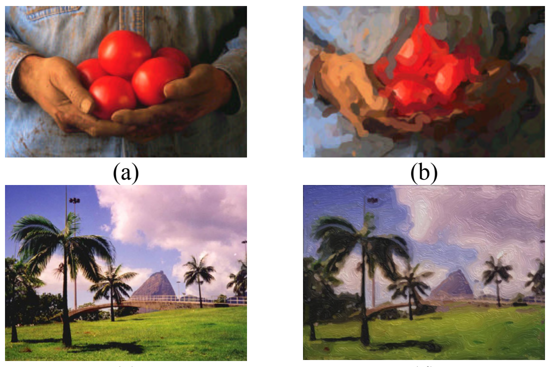

Fig. 1: The images created by Hertzmann [2] and Hertzmann [3]. (a) and (b) Effect of watercolor painting [2]. (c) and (d) Effect of oil painting [3].

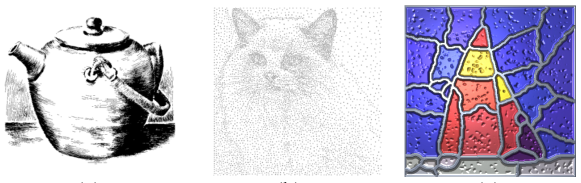

Fig. 2: Some types of art images. (a) A pen-and-ink drawing from Salisbury [4]. (b) A stipple image from Mould [5]. (c) A stained glass image from Mould [6].

Another type of art image is mosaic image. Each mosaic image is composed of small shapes, such as squares, circles, triangles, and so on. Different from using fixed orientations for tile arrangements in traditional mosaic generation schemes, Hausner [7] creates a new type of tile mosaic image by placing tiles to follow the edges in the input image to make the created art image smoother. Fig. 3 shows some examples from Hausner [7]. Another important criterion for art image creation is to limit the number of strokes so that the resulting image looks like an abstract painting, such as the images shown in Fig. 4 which come from Haeberli [8]. Besides, Song, et al. [9] produces an abstract synthetic art by fitting shapes like triangles or rectangles to the regions in segmented images, like the ones shown in Fig. 5.

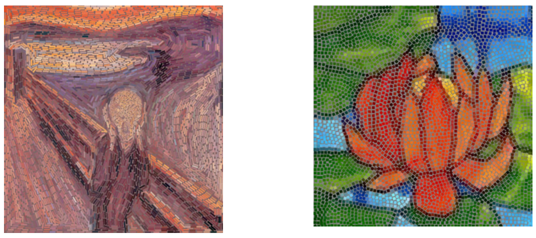
Fig. 3: Tile mosaic images created by Hausner [7].

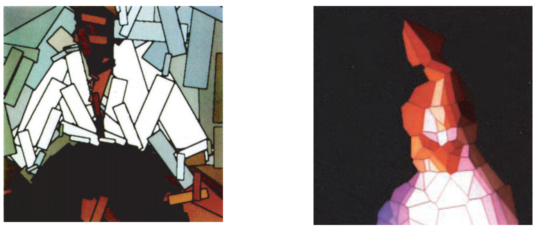
Fig. 4: Images created by Haeberli's method [8].

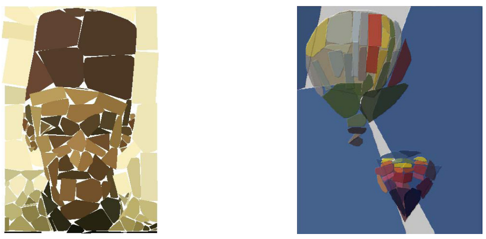
Fig. 5: Images created by Song, et al. [9].

In this study, we try to use the line feature used in Cubism paintings to create an abstract type of line-dominated art image, called *line-based Cubism-like image*. Two examples of such images created in this study are shown in Fig. 6.

On the other hand, data hiding is a technique which embeds data imperceptibly into cover images, so that people will not perceive the existence of the hidden data. Data hiding techniques often utilize the weaknesses of the human visual system in differentiating small color or grayscale differences. A well-known method is least significant bit (LSB) modification which changes the LSBs of the pixels of an image to embed information, like Chan and Cheng [10]. Another is the contrast-keeping data embedding scheme proposed by Wu and Tsai [11]. Also, to achieve recoverability of the cover image from the stego-image, which requires lossless data embedding, the most common approach is to compress a portion of the cover image and embed the result with the intended payload into the cover image, such as Fridrich, et al. [12] and Awrangjeb and Kankanhalli [13]. Another approach is to manipulate a group of pixels as a unit to embed a bit of information, like Tian [14] and Vleeschouwer, et al. [15]. A third approach is to use the technique of histogram shifting which can embed large volumes of data, e.g., Ni, et al. [16] and Lee and Tsai [17]. In this study, we use a new scheme of keeping average region colors unchanged to achieve the goal of lossless data hiding. Note that there exist very few lossless data hiding techniques so far.

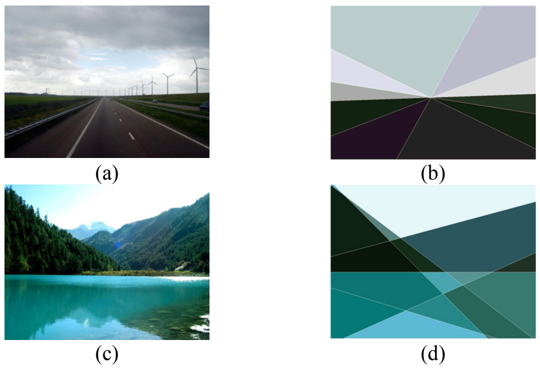

Fig. 6: Two examples of line-based Cubism-like images created in this study.

Moreover, the combination of data hiding and art image creation techniques is a new idea for information hiding applicatios. Techniques based on this idea utilize the characteristics of the creation process of the art image to embed extra information in the generated image. Attracted by the art exhibited by the image, people will pay no attention to the hidden secret data in the art image. Due to this way of camouflage, secret data can be kept or transmitted covertly and securely. In this study, we hide secret message in the proposed Cubism-like image during the image creation process by changing the colors of the pixels in image regions *slightly* while keeping the average colors of the regions *unchanged*. The color differences in the resulting image are difficult to be found by attackers because of the weaknesses of the human visual system in discriminating small color changes.

In the remainder of this paper, we describe the proposed technique for creating the line-based Cubism-like art image in Section 2, the proposed data hiding technique in Section 3, followed by conclusions in Section 4. Experimental results are also shown in Sections 2 and 3 to demonstrate the feasibility of the proposed method.

2. PROPOSED LINE-BASED CUBISM-LIKE IMAGE CREATION PROCESS

2.1. Idea of Line-based Cubism-like Image Creation

Cubism artists transform a natural scene into geometric forms by breaking up, analyzing, and re-assembling objects in the scene. In addition, with the scene objects rearranged to intersect at random angles, each painting of Cubism appears to be composed of intersecting lines and fragmented shapes in an abstract style. The idea of the proposed art image creation method is inspired by these concepts of Cubism, as mentioned previously.

In the creation process of a line-based Cubism-like image from a given source image, at first we find the prominent line segments in the image by edge detection and the Hough transform. Then, we connect the line segments and extend them to reach the image boundaries. Finally, we generate the desired art image via the operations of line segment merging and region re-coloring. This process accomplishes the goal of transforming the input image into an abstract form since the lines of the created Cubism-like image tend to constitute the skeleton of the objects in the source image as observed from our experimental results.

2.2. Creation of Line-based Cubism-like Image

The proposed art image creation process is composed of two major procedures. Basically, in the process of line detection, we find edges in the source image by Canny edge detection [18] and the Hough transform [19]. Then, we filter out short line segments, as well as line segments which are too close to other longer lines. Then we extend and recombine the remaining prominent line segments to form the skeleton of the objects in the source image. Finally, a desired Cubism-like image is created by coloring the resulting regions. The detail is described in the following algorithm.

```
Algorithm 1: line-based Cubism-like image creation.
Input: a source image $S$, and two threshold values — 
       the minimum line segment length $L_{\min}$ and the
       minimum between-line distance $D_{\min}$.
Output: a line-based Cubism-like image $C$.
Steps.
Stage 1 --- creating crossing-image lines.
Step 1. Perform Canny edge detection to find the edge
        points in source image $S$, resulting in a new
        image $S'$.
Step 2. Perform the following steps to find prominent
        line segments in $S'$.
    2.1 Find line segments $L_1$, $L_2$, …, $L_m$, in $S'$ by
        applying the Hough transform on $S'$,
        yielding a second new image $S''$ of the line
        type.
    2.2 Select those line segments in $S''$ with
        lengths larger than threshold $L_{\min}$.
    2.3 Compare every line pair $L_i$ and $L_j$ with $i \neq j$
        in $S''$ and if the distance $D_{ij}$ between $L_i$ and
        $L_j$ is smaller than $D_{\min}$, then delete $L_i$ if the
        length of $L_i$ is smaller than that of $L_j$; or
        delete $L_j$, otherwise.
Step 3. Extend each of the remaining line segments in
        $S''$ to the boundaries of $S''$, and regard the
        source image $S$ as being partitioned by these
        extended lines to form regions.
Stage 2 --- re-coloring image regions.
Step 4. Create a binary image $T$ of the size of $S$ with
        initial pixel values all set to be 0.
Step 5. Fill the value of 1 into those pixels in $T$ which
        correspond to those lying on each of the
        extended line segments in $S''$.
Step 6. Perform following steps to re-color the regions
        in $S$.
    6.1 Perform region growing in the binary image
        $T$ in a raster-scan order, and segment out 0-
        valued regions, $R_1$, $R_2$, …, $R_k$, each of
        which is enclosed by a group of 1-valued
        line segments in $S''$.
    6.2 Compute the area $A_i$ of each segmented
        region $R_i$ in $T$ and the average RGB color
        values ($C_{ir}$, $C_{ig}$, $C_{ib}$) of the corresponding
        region $R_i'$ in $S$ using $A_i$, and re-color each
        pixel in $R_i'$ of $S$ by the color values ($C_{ir}$, $C_{ig}$,
        $C_{ib}$), $i = 1, 2, …, k$.
    6.3 Re-color all lines in $S$ corresponding to the
        1-valued extended lines in $T$ by the white
        color.
Step 7. Take the final $S$ as the desired line-based
        Cubism-like image $C$.
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2.3. Experimental Results

According to the above discussions, we see that different selections of the two threshold values $L_{\min}$ and $D_{\min}$ will result in totally different effects in the created art images. However, it is difficult to decide which result is better than the others because the decision is obviously dependent on people's different feelings of art. Therefore, in this study we just offer a series of results yielded by the use of different sets of thresholds for the user to inspect and choose. Specifically, we use the three values of 0.5/10, 1/10, and 2/10 times the length of the longer image boundary as the values for each of the thresholds $L_{\min}$ and $D_{\min}$. As a result, each threshold has three choices, resulting in nine choices of the two threshold values. Then, we generate nine art images, each corresponding to one of the nine threshold combinations, for the user to choose his/her favorite one. An example is shown in Fig. 7.

3. PROPOSED DATA HIDING TECHNIQUE

3.1. Idea of Proposed Technique

In the proposed Cubism-like image creation process as presented by Algorithm 1 above, the main idea is to re-color the pixels in each image region with the average color of all the pixels in the region with the resulting image visually looking like the original one.

About the proposed data hiding technique, it is pointed out first that due to the nature of the human visual system, people cannot sense small changes in the appearance of a color image, such as color alternations or edge shiftings. Therefore, the proposed data hiding technique is designed to hide a secret message into a cover image — a line-based cubism-like image generated by the proposed creation method described previously — by changing slightly the *rgb* color values of the pixels in each region of the cover image. As a result, people will not be able to distinguish the difference between the cover image and the stego-one. It is in this way that we achieve the goal of data hiding in the proposed line-based Cubism-like art image without arousing suspicions from hackers.

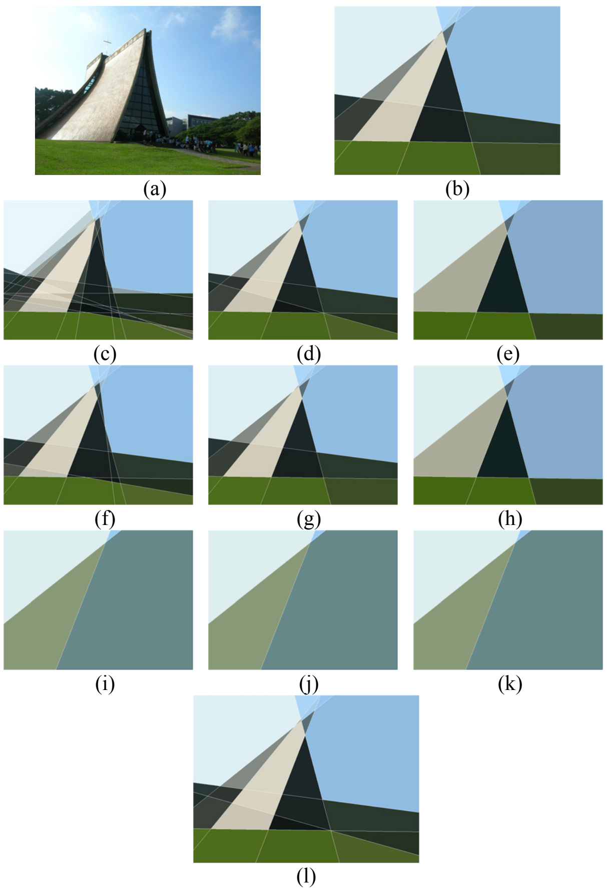


Fig. 7: Experimental results. (a) A source image with size 1024×768. (b) Initial $D_{\min}$ = 102 and initial $L_{\min}$ = 102. (c) ($D_{\min}$, $L_{\min}$) = (51, 51). (d) ($D_{\min}$, $L_{\min}$) = (51, 102). (e) ($D_{\min}$, $L_{\min}$) = (51, 204). (f) ($D_{\min}$, $L_{\min}$) = (102, 51). (g) ($D_{\min}$, $L_{\min}$) = (102, 102). (h) ($D_{\min}$, $L_{\min}$) = (102, 204). (i) ($D_{\min}$, $L_{\min}$) = (204, 51). (j) ($D_{\min}$, $L_{\min}$) = (204, 102). (k) ($D_{\min}$, $L_{\min}$) = (204, 204). (l) A better choice of 9 images to fit the abstract style of Fig. 1(a) is $D_{\min}$=102 and $L_{\min}$=51.

Furthermore, for the reason of achieving reversibility in the hidden data extraction process, a *reversible* region re-coloring technique, which keeps the average color of each region unchanged, is proposed. Consequently, we can restore the color information of the pixels in the stego-image perfectly after extracting the secret messages embedded in them. More specifically, in the proposed data hiding process, after the step of hiding message bits into a color channel, the pixel colors in a region will be changed via color shifting, and the average color of the region will also be influenced. In order to keep the average color unchanged as desired, we limit the number of message bits embedded into the region. For this purpose, it is found in the study that the property of *rounding-off* of integer computation may be utilized. Specifically, when computing the average color C of a region, all the computed results in the range between $C - 0.5$ and $C + 0.5$ will be rounded to be an identical value since color values used in this study are *integer numbers*. Accordingly, we can acquire the maximum number of embedded bits in a region as derived in the following.

Assume that A is the total number of pixels in a region R (in unit of pixel), C_{r1}, C_{r2}, …, C_{rn} are the *r*-color values of the n pixels in region R, and C_r is the average *r*-color value of region R. Also, let N_0 and N_1 denote the total numbers of bits of 0's and 1's embedded in R. At first, the average *r*-color value C_r of all the pixels in R may be computed by

$$C_r = (C_{r1} + C_{r2} + \ldots + C_{rn})/A.$$

Therefore, we have

$$C_rA = C_{r1} + C_{r2} + \ldots + C_{rn}.$$

Furthermore, we hide the secret message bits by shifting the average *r*-color value of each pixel in this study. We assume that when hiding a bit of 0 into a pixel P in region R with average *r*-color value C_r, the pixel's color C_r is decreased by 1; and when hiding a bit of 1 into P, the pixel's color C_r is increased by 1. Therefore, if N_0 0's and N_1 1's are embedded into the pixels of region R, then it can be figured out that the average *r*-color value C_r of R will increase for the amount of $N_1 - N_0$ (or equivalently, decrease for the amount of $N_0 - N_1$), so that the new average color C_r' becomes:

$$\begin{aligned} C_r' &= (C_{r1} + C_{r2} + \ldots + C_{rn} + N_1 - N_0)/A \\ &= (C_rA + N_1 - N_0)/A. \end{aligned}$$

To keep the new average color C_r' equal to the original one C_r, we have to limit the values of the two numbers N_1 and N_0 according to the above-mentioned rounding-off property, resulting in the following formula:

$$C_r - (1/2) \le C_r' = (C_rA + N_1 - N_0)/A < C_r + (1/2)$$

which can be reduced to be

$$-A/2 \le N_1 - N_0 < A/2. \qquad (1)$$

As a summary, the values of N_1 and N_0 together are limited by the total number A of pixels in the region, implying that the data hiding capacity is also restricted by it. In the best case, we know that the maximum number of embeddable bits in a region is just the number A of pixels in the region, that is,

$$N_1 + N_0 = A. \qquad (2)$$

Now, according to Equations (1) and (2), we can derive the ranges of N_1 and N_0 to be as follows (the details omitted):

$$A/4 \le N_0 < 3A/4, \qquad (3)$$
$$A/4 \le N_1 < 3A/4. \qquad (4)$$

In the extreme case where the digit sequence is composed of all 0's or all 1's, the upper bound of the data hiding capacity will be reached, which is $\lfloor A/2 \rfloor - 1$, as can be figured out from Equation (1).

In this study, we keep the average region color unchanged for two reasons. The first, as mentioned previously, is to make possible recovery of the region information in the data extraction process, where we use the average color as a basis to extract the hidden secret message. The other reason is to yield a visually mosaic effect so that the region color that people see is *almost the same*, despite of the color shifting inside the region.

3.2. Proposed Data Hiding Process

The proposed data hiding process, which is based on the creation process of the line-based Cubism-like image, is described in detail in this section. As described in the last step of Algorithm 1, we re-color each region of the input image by the average color of the region to generate the desired Cubism-like image. For the purpose of hiding data in the generated Cubism-like image, we try to modify this re-coloring process to achieve secret message hiding.

Specifically, the data hiding process is composed of two main stages. First, we transform the secret massage into a digit sequence and append an ending pattern (with at least one digit) at the end of the digit sequence to keep the sequence length a multiple of three. By the ending pattern, we can determine where the massage ends in a sequence of extracted bits in the message extraction process. Next, we try to obtain the information of two parameters of each region, namely, the region area and the average *rgb* color values in the region, by performing Algorithm 1. Furthermore, we use a secret key to randomize the order of re-coloring of the regions in the input image, and take the resulting new sequence as the order for data hiding. For each region, we compute the maximum data hiding capacity. In order to keep the average *rgb* color of the region unchanged, we limit the embedded amount of message bits in each region as described previously. After getting the maximum data hiding capacity, we embed the message bits by shifting the color values of the pixels in each region according to the above-mentioned data hiding order. After the digit sequence is exhausted, there might exist regions in which no message bit is embedded. We deal further with these intact regions to keep the coloring style of all regions consistent. By creating a new binary string whose size is the upper bound of the data hiding capacity and constituting randomly a string with 0's and 1's by the secret key, we use the same process to re-color the pixels in these regions according to the resulting binary string. At the end, a stego-image is generated with the secret message embedded. The detailed algorithm to implement these steps is given as follows.

Algorithm 2: ***embedding a secret message into a line-based Cubism-like image.***

Input: a cover image S, a secret key K, a secret message M in character form, and two threshold values — the minimum line segment length $L_{\min}$ and the minimum between-line distance $D_{\min}$.

Output: a stego-image I into which M is embedded.

Steps.

Stage 1 --- embedding a secret message M.

Step 1. Transform the secret massage M in character form into a bit sequence M', and randomize the bits in M' by the secret key K.

Step 2. Transform each bit of M' into a digit, resulting in a digit sequence M'', and append an ending pattern with at least one and no more than three identical digits d_e other than 0's and 1 at the end of M'' to form a new digit sequence with its length being a multiple of three.

Step 3. Divide M'' into a sequence of 3-digit segments $m_1, m_2, \ldots, m_n$.

Step 4. Perform Algorithm 1, using the input cover image S as the source image, to obtain the information of two parameters of the regions $R_1, R_2, \ldots, R_k$ in S, namely, the areas $A_1, A_2, \ldots, A_k$ and the average *rgb* color values (C_{1r}, C_{1g}, C_{1b}), (C_{2r}, C_{2g}, C_{2b}), …, (C_{kr}, C_{kg}, C_{kb}) of the regions $R_1, R_2, \ldots, R_k$, respectively.

Step 5. Rearrange randomly the coloring order of the regions by the secret key K, resulting in a new coloring sequence $C_s = \{R_1', R_2', \ldots, R_k'\}$; and change accordingly the corresponding orders of the areas and the average *rgb* color values, resulting in the new orders of $A_1', A_2', \ldots, A_k'$ and $(C_{1r}', C_{1g}', C_{1b}')$, $(C_{2r}', C_{2g}', C_{2b}')$, …, $(C_{kr}', C_{kg}', C_{kb}')$, respectively.

Step 6. Calculate the maximum data hiding capacity Q_i of each region R_i' in accordance with the new coloring sequence C_s by the following steps with the initial value of Q_i being set to be zero.

6.1 Assign each 3-digit segment $m_t = d_r d_g d_b$ of the digit sequence M'' into one of six groups $N_{r0}, N_{r1}, N_{g0}, N_{g1}, N_{b0}$, and N_{b1} in the following way:

(a) increase N_{r0} by 1 if $d_r = 0$; and increase N_{r1} by 1 if $d_r = 1$;

(b) increase N_{g0} by 1 if $d_g = 0$; and increase N_{g1} by 1 if $d_g = 1$;

(c) increase N_{b0} by 1 if $d_b = 0$; and increase N_{b1} by 1 if $d_b = 1$.

6.2 Compute the maximum data hiding capacity Q_i of each region R_i' by the following operations.

(a) If $N_{r1} - N_{r0} \geq A_i'/2$ or $N_{r1} - N_{r0} < -A_i'/2$, take the current Q_i to be the maximum data hiding capacity.

(b) If $N_{g1} - N_{g0} \geq A_i'/2$ or $N_{g1} - N_{g0} < -A_i'/2$, take the current Q_i to be the maximum data hiding capacity.

(c) If $N_{b1} - N_{b0} \geq A_i'/2$ or $N_{b1} - N_{b0} < -A_i'/2$, take the current Q_i to be the maximum data hiding capacity.

(d) Increase the data hiding capacity Q_i by 3 if Q_i has not been set to be the maximum data hiding capacity.

6.3 Repeat Steps 6.1 and 6.2 until Q_i has been taken to be the maximum data hiding capacity or until the digit sequence M'' is exhausted.

Step 7. Perform the following steps to embed the secret message digits into each region R_i'.

7.1 Reorder randomly the pixels in R_i', which is initially in a raster-scan order, into a *hiding sequence* $H_s = \{p_1, p_2, \ldots, p_t\}$, by using the secret key K and the index i of R_i' in the coloring sequence C_s as the seed for the randomization process.

7.2 Embed each 3-digit segment $m_t = d_r d_g d_b$ of the digit sequence M'' into a pixel p_j of R_i' according to the hiding sequence H_s in the following way.

(a) Obtain new average *rgb* color values (C_{jr}'', C_{jg}'', C_{jb}'') of each pixel p_j in S by shifting in order the original average *rgb* color values (C_{jr}', C_{jg}', C_{jb}') of p_j in the following way, where $h = r$, g, and b:

i. decrease $C_{jh}'$by 1 if $d_h = 0$;

ii. increase C_{jh}' by 1 if $d_h = 1$;

iii. do nothing C_{jh}' if $d_h = d_e$ (the ending pattern digit).

(b) Re-color the pixel p_j by the new *rgb* color values (C_{jr}'', C_{jg}'', C_{jb}'').

(c) Decrease the data hiding capacity Q_i by 3.

(d) Repeat the above two steps until the maximum data hiding capacity Q_i is exhausted.

Step 8. Repeat Steps 6 and 7 if the digit sequence of M'' is not exhausted.

Stage 2 --- dealing with intact regions.

Step 9. Perform the following steps to deal with each intact region R_l' with area A_l' which has not been used for message bit embedding so far.

9.1 Use the secret key K to create a binary string B with size $\lfloor A_l'/2 \rfloor - 1$ for R_l' , which is composed of a random sequence of 0's and 1's.

9.2 Perform Steps 6 through 8 to re-color the pixels of R_l' to embed the binary string B.

Step 10. Take the final S as the desired stego-image I.

In the above algorithm, wrap-around problems might occur in Steps of 7.2(a)-i and 7.2(a)-ii when the average color value in a color channel is 255 or 0. In this case, we will obtain a bad stego-image with some noise (black or white image points) after 1 is added to 255 or 1 is subtracted from 0. To avoid such extreme cases, we adjust the extreme average color values of 255 and 0 to be 254 and 1, respectively, before data hiding. Such slight color alternations in the generated stego-image cause nearly no visual effect to the human vision but can solve the wrap-around problem.

3.3. Secret Extraction Process

In the proposed secret message extraction process, first we recover the coloring sequence in the stego-image. By a region growing scheme, we get the information of the regions with an initial order sequence. Then, we retrieve the coloring sequence by using the secret key. Moreover, in the process of region growing, we also obtain the area and the average color of each region in the stego-image. Based on the average region color values, we can retrieve accordingly the secret message embedded in a region in the stego-image by comparing the average region color and those of the pixels in the region. The algorithm of secret data extraction is described in detail as follows.

Algorithm 3: ***extracting a secret message from a stego-image.***

Input: a stego-image S, and a secret key K identical to that used in Algorithm 2.

Output: the secret message M embedded in S.

Steps.

Stage 1 --- retrieving information of the stego-image.

Step 1. Perform region growing in a raster-scan order to segment out regions, R_1, R_2, …, R_k, in S, and obtain the information about the area A_1, A_2, …, A_k and the average *rgb* color values (C_{1r}, C_{1g}, C_{1b}), (C_{2r}, C_{2g}, C_{2b}), …, (C_{kr}, C_{kg}, C_{kb}) of the regions, respectively.

Step 2. Retrieve the coloring order of regions by the secret key K, denote the result as $C_s = \{R_1', R_2', \ldots, R_k'\}$, and change the corresponding orders of the areas and the average *rgb* color values of the regions, resulting in the new order sequences of areas A_1', A_2', …, A_k' and average color values (C_{1r}', C_{1g}', C_{1b}'), (C_{2r}', C_{2g}', C_{2b}'), …, (C_{kr}', C_{kg}', C_{kb}'), respectively.

Stage 2 --- extracting the embedded data.

Step 3. Create an *empty* digit sequence Q initially.

Step 4. Perform the following steps to extract the secret message M from S.

4.1 Randomize the pixel order in R_i', which initially is in a raster-scan order, and denote the result as a recovered sequence $H_s = \{p_1, p_2, \ldots, p_T\}$, using the secret key K and the index of R_i' in the coloring sequence C_s together as the seed of the randomization process.

4.2 Obtain the *rgb* color values of each pixel p_j of R_i' according to sequence H_s and denote them by (C_{jr}'', C_{jg}'', C_{jb}'').

4.3 Acquire three digits Q_{jr}, Q_{jg}, and Q_{jb} from the differences between the *rgb* color values (C_{jr}'', C_{jg}'', C_{jb}'') of each pixel p_j and the average *rgb* color values (C_{ir}', C_{ig}', C_{ib}') of region R_i', respectively, by the following way:

(a) if any of the color values (C_{jr}'', C_{jg}'', C_{jb}'') is smaller than the corresponding average color value in (C_{ir}', C_{ig}', C_{ib}'), then set the corresponding value Q_{jr}, Q_{jg}, or Q_{jb} to be 0;

(b) if any of the color values (C_{jr}'', C_{jg}'', C_{jb}'') is larger than the average color (C_{ir}', C_{ig}', C_{ib}'), then set the corresponding value Q_{jr}, Q_{jg}, or Q_{jb} to be 1;

(c) if any of the color values in (C_{jr}'', C_{jg}'', C_{jb}'') is equal to the corresponding average color value in (C_{ir}', C_{ig}', C_{ib}'), then set the corresponding value in (Q_{ir}, Q_{ig}, Q_{ib}) to be d_e (the ending pattern digit).

4.4 Store the three digits Q_{ir}, Q_{ig}, and Q_{ib} into Q in order.

4.5 Repeat Steps 4.1 through 4.4 until a value in Q equal to d_e (the ending pattern digit) is encountered.

Step 5. Use the secret key K to reorder Q.

Step 6. Transform Q into character form as the desired secret message M.

3.4. Experimental Results

Figs. 8 through 13 show some experimental results of applying the proposed data hiding method to two images. Figs. 8(a) and 11(a) are the source images. Figs. 8(b) and 11(b) are the generated Cubism-like images with no secret message embedded. Fig. 8(c) is a stego-image into which a secret message "Meet me at 21:30. See you." has been embedded with the secret key "test." Fig. 11(c) is a stego-image into which a secret message "Hi, I am Helen. Nice to meet you!" has been embedded with the secret key "door." The secret message can be retrieved only when the right key is used in the secret message extraction process, like the results of Figs. 9 and 12. If a wrong key is used in the secret extraction process, the extraction work will fail, as shown by the examples in Figs. 10 and 13.

4. CONCLUSIONS

In this paper, a new method of combining art image generation and data hiding to enhance the camouflage effect for various information hiding applications is proposed. At first, a new type of computer art, called line-based Cubism-like image, and a technique to create it automatically from a source image have been proposed. The method finds line segments in the source image by the Canny edge detection technique and the Hough transform, combines nearby line segments, extends the remaining lines to the image boundaries, and re-color the created regions by their average colors, to create an abstract type of the original source image as the desired art image. Then, by utilizing the characteristics of the Cubism-like image creation process, a data hiding technique has been proposed. Based on the minimum color shiftings of the values of ±1, the technique embeds message data into the pixels of the regions of the generated art image while keeping the average region colors unchanged. The data embedding process is proved to be lossless by theorems so that the cover image can be recovered perfectly after the embedded message data are extracted.

The proposed method has several merits. First, it generates Cubism-like images as stego-images to distract the hacker' s attention to the message data embedded in them. Also, by using the minimum color shiftings of ±1 to embed data bits, the resulting pixels' color differences between the generated Cubism-like image and the stego-image are so small that a hacker will take no notice of the existence of the hidden data. Consequently, the proposed data hiding technique is very suitable for use in covert communication or secret keeping. Furthermore, four measures of randomization of the input message data and the processing order of them with a secret key and several random-number generating functions have been adopted in the proposed method. This enhances greatly the security of the proposed method.

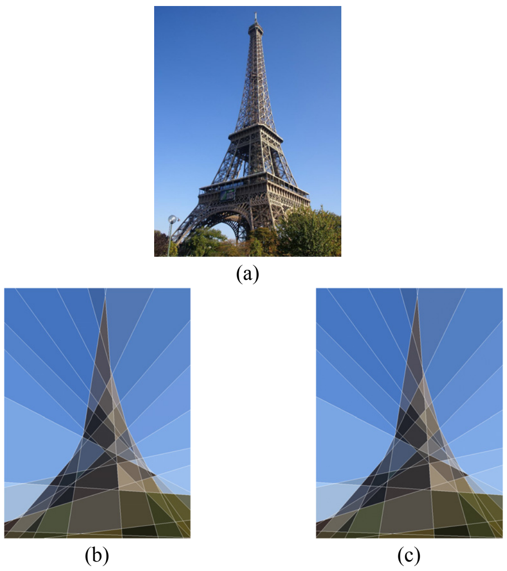
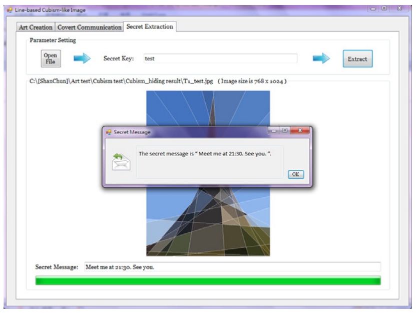


Fig. 8: An experimental result. (a) Source image. (b) A Cubism-like image without secret message embedding. (c) A stego-image of (a) into which secret messages are hidden.



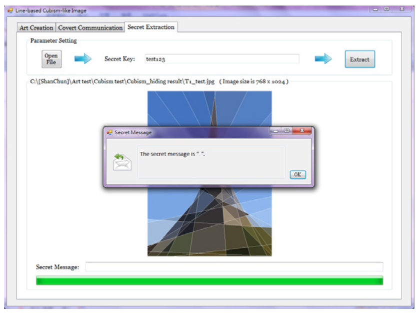
Secret Key: test

C:\[ShanChun]\Art test\Cubism test\Cubism_hiding result\T1_test.jpg (Image size is 768 x 1024)

The secret message is " Meet me at 21:30. See you. ".

Secret Message: Meet me at 21:30. See you.

Fig. 9: Extracting secret message with the right secret key.



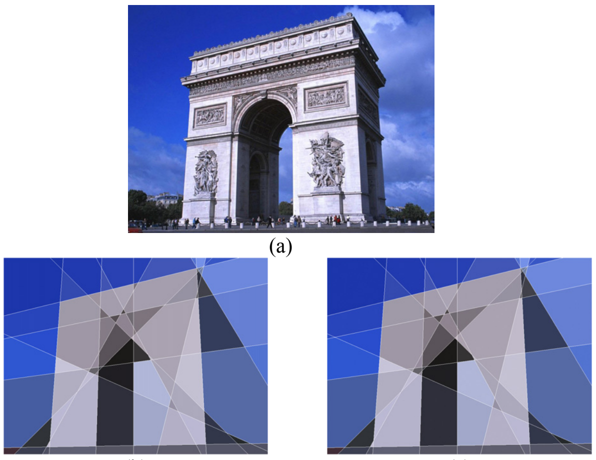
Secret Key: test123

C:\[ShanChun]\Art test\Cubism test\Cubism_hiding result\T1_test.jpg (Image size is 768 x 1024)

The secret message is " ".

Secret Message:

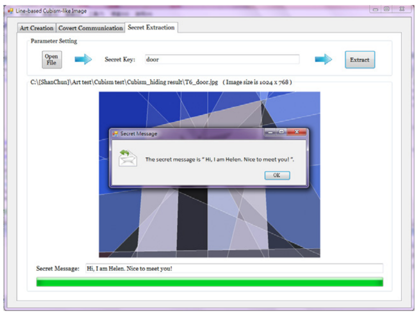
Fig. 10: Extracting incorrect message with a wrong key.



(a)

(b) (c)

Fig. 11: Another experimental result. (a) Source image. (b) A Cubism-like image without secret message embedding. (c) A stego-image of (a) into which secret messages are hidden.



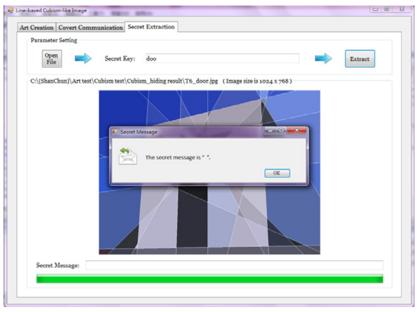
Secret Key: door

C:\[ShanChun]\Art test\Cubism test\Cubism_hiding result\T6_door.jpg (Image size is 1024 x 768)

The secret message is " Hi, I am Helen. Nice to meet you! ".

Secret Message: Hi, I am Helen. Nice to meet you!

Fig. 12: Extracting secret message with a right key.



Secret Key: doo

C:\[ShanChun]\Art test\Cubism test\Cubism_hiding result\T6_door.jpg (Image size is 1024 x 768)

The secret message is " ".

Secret Message:

Fig. 13: Extracting incorrect message with a wrong key.

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