國立交通大學

多媒體工程研究所

碩 士 論 文

電腦藝術畫的自動產生與其在資料隱藏及浮水印之應用

Automatic Generation of Computer Art Images and Their Uses for Data Hiding and Watermarking Applications

研 究 生：王宗志

指導教授：蔡文祥　教授

中 華 民 國 九 十 六 年 六 月

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摘要

在本論文中，我們研究了三種藝術影像的自動產生與相關資訊隱藏技術。這三種不同類型的藝術影像分別是不規則六邊形畫、重疊馬賽克畫，以及多尺寸馬賽克畫。在不規則六邊形畫中，我們找到了兩種可供資訊隱藏的屬性，分別是六邊形的兩頂點與其內部顏色。藉由調整此兩頂點的座標位置及修改六邊形的內部顏色，我們可將秘密資訊及浮水印隱藏於不規則六邊形畫之中，達到秘密訊息傳輸與版權保護之目的。在重疊馬賽克畫中，我們利用相鄰兩小圖之重疊程度來達到資訊隱藏的目的。藉由改變相鄰小圖重疊大小的技巧，我們可以隱藏 0~7 個位元於相鄰兩小圖的 X 及 Y 方向重疊關係之中。在多尺寸馬賽克畫中，我們利用大圖及小圖兩種尺寸的圖來達到藏入秘密訊息之目的，而相鄰兩圖間並不會有裂縫或重疊的情形發生。我們並透過實驗結果來證明這些方法的實用性。

Automatic Generation of Computer Art Images and Their Uses for Data Hiding and Watermarking Applications

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ABSTRACT

Three types of art images are created in this study, namely, irregular-hexagonal-tiled image, tile-overlapping mosaic image, and variable-sized mosaic image. Methods for automatic generation of these types of art images and data hiding in them are proposed. For irregular-hexagonal-tiled images, we find two features for information hiding, namely, two specific vertices and inner colors of tiles. We can hide secret messages and watermarks into images by adjusting the locations of the two specific vertices and modifying the inner colors of hexagons. The methods may be used for secret communication and copyright protection. For tile-overlapping mosaic images, we utilize the overlapping pixels of adjacent tile images to implement the data hiding work. We can hide zero to seven bits into a pair of tile images by changing the overlapping degrees of adjacent tile images. For variable-sized mosaic images, we utilize two sizes of tile images to implement the data hiding work. We hide data bits into the tile images by changing the sizes of them dynamically without creating overlapping areas in the resulting stego-image. Experimental results show the feasibility of the proposed methods and their applications for data hiding and watermarking.

ACKNOWLEDGEMENTS

I am in hearty appreciation of the continuous guidance, discussions, support, and encouragement received from my advisor, Dr. Wen-Hsiang Tsai, not only in the development of this thesis, but also in every aspect of my personal growth.

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Finally, I also extend my profound thanks to my family for their lasting love, care, and encouragement. I dedicate this dissertation to my parents.

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Chapter 1
Introduction

1.1 Motivation of Study

With the growth of networks, interpersonal communication is more popular than before. Exchanges of digital files have become more convenient and much faster via the Internet. However, it may bring many drawbacks in copyright protection of digital files. People can easily modify or tamper with digital contents on the network, or even steal secrets of others! If the information is extremely secret like military information or the password of a coffer, then it should be protected carefully so as not to be stolen. In order to avoid leaking a secret during the transmission process, how to protect secret digital information has become an urgent issue.

Different from the traditional information hiding technique, we try to hide information during the art image creation process in this study. It is desired to combine techniques of information hiding and art image creation for various applications. We want to create images which are artistic in appearance and technically useful for information hiding. We will create three different kinds of art images. We name them *irregular-hexagonal-tiled image*, *tile-overlapping mosaic image, and variable-sized mosaic image,* respectively. Each of them will be introduced in the following chapters in detail.

1.2 Overview of Proposed Methods

1.2.1 Definitions of Terms

Before describing the proposed methods, some definitions of terms are given to facilitate understanding the remainder of this thesis.

1. *Original image*: An original image is an image chosen to produce an art image.
2. *Art image*: An art image is a non-photorealistic image created from an original image. In this study, an art image may be an irregular-hexagonal-tiled image, a tile-overlapping mosaic image, or a variable-sized mosaic image.
3. *Tile image*: A tile image is a small image, similar to a small specific block of the original image.
4. *Mosaic image*: A mosaic image is obtained by arranging a large number of tile images in a certain way to suggest a larger image when seen from a distance.
5. *Tiling style*: A tiling style includes the assigned size and shape of a tile image.
6. *Irregular-hexagonal-tiled image*: An irregular-hexagonal-tiled image is an image composed of many pieces of irregular hexagons.
7. *Tile-Overlapping mosaic image*: A tile-overlapping mosaic image is a mosaic image obtained by arranging a large number of tile images which are overlapping with each other.
8. *Variable-Sized mosaic image*: A variable-sized mosaic image is a mosaic image obtained by arranging a large number of tile images which are with different sizes.
9. *Target image*: A target image is a sub-image of an original image obtained by dividing the original image into small blocks.
10. *Cover image*: A cover image is a medium image for information hiding applications.

11. *Stego-image*: A stego-image is produced by embedding a watermark or some data into a cover image.
12. *Creation process*: A creation process produces an art image from an original image.
13. *Embedding process*: An embedding process is a process to implant data into an art image.
14. *Extraction process*: An extraction process is a process to get hidden data from a stego-image.

1.2.2 Brief Descriptions of Proposed Methods

In this study, we propose creation methods for three kinds of art images. During the creation process, we achieve information hiding applications by utilizing the characteristics of these art images. We will state both creation and information hiding methods for each art image. The methods we propose are:

(1) creation of irregular-hexagonal-tiled images and information hiding in them;

(2) creation of tile-overlapping mosaic images and information hiding in them;

(3) creation of variable-sized mosaic images and information hiding in them.

1.2.3 Brief Description of Proposed Method for Creation of Irregular-Hexagonal-Tiled Images and Information Hiding in Them

The proposed process of data hiding in irregular-hexagonal-tiled images is shown in Figure 1.1. According to the flowchart, first of all, we create an irregular-hexagonal-tiled image, which will be discussed thoroughly in Section 3.2. Second, we transform given data into a bit sequence which will be hidden. The given data might be a watermark, a secret message, or any digital data which you want to transmit covertly. Third, we use a secret key to disarrange a bit sequence, and then conduct an information hiding process. A detailed discussion of the proposed method for data hiding in irregular-hexagonal-tiled images will be stated in Section 3.3.3.

The proposed process of data extraction from irregular-hexagonal-tiled images is shown in Figure 1.2. After checking the secret key and performing the proposed process of data extraction, we get embedded secret information from the irregular-hexagonal-tiled image. The proposed method for data extraction from irregular-hexagonal-tiled images will be thoroughly discussed in Section 3.3.4.

1.2.4 Brief Review of Adopted Methods for Mosaic Images Creation

A method [17] of mosaic image creation is adopted in this study and a flowchart of it is shown in Figure 1.3. It can be divided into two parts. One is tile image database creation; the other is mosaic image generation. The first part is off-line in nature, and the other is on-line. We will describe the detail of the adopted method for mosaic image creation in Section 4.1.

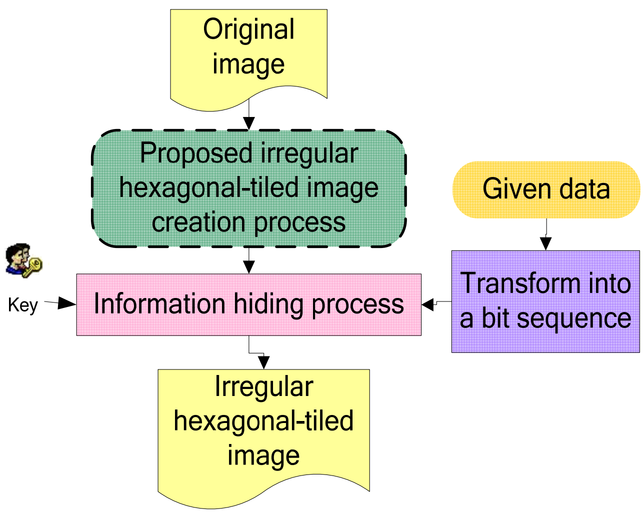


Figure 1.1 Proposed process of information hiding in irregular-hexagonal-tiled images.

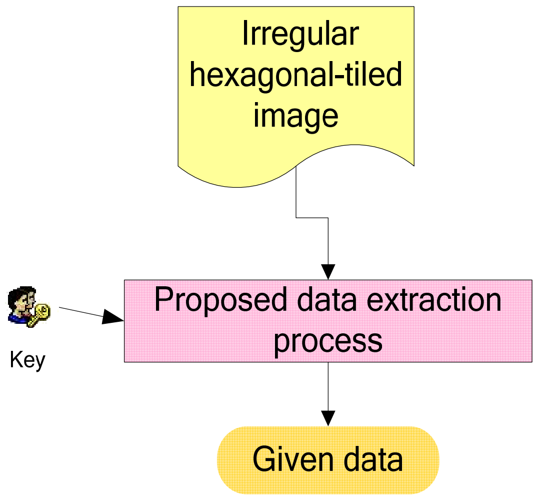


Figure 1.2 Proposed process of data extraction from irregular-hexagonal-tiled images.

1.2.5 Brief Description of Proposed Method for Creation of Tile-Overlapping Mosaic Images and Information Hiding in Them

The proposed process of data hiding in tile-overlapping mosaic images is shown in Figure 1.4. According to the flowchart, first of all, we create a tile-overlapping mosaic image, which will be discussed thoroughly in Section 4.3. Second, we transform given data into a bit sequence which will be hidden. Third, we use a secret key to disarrange a bit sequence, and then conduct the information hiding process. A detailed discussion of information hiding in tile-overlapping mosaic images will be stated in Section 4.4.2. The proposed process of data extraction from tile-overlapping mosaic images is shown in Figure 1.5. After checking the secret key and performing the proposed process of data extraction, we can get secret information from the tile-overlapping mosaic image. The method will be thoroughly discussed in Section 4.4.3.

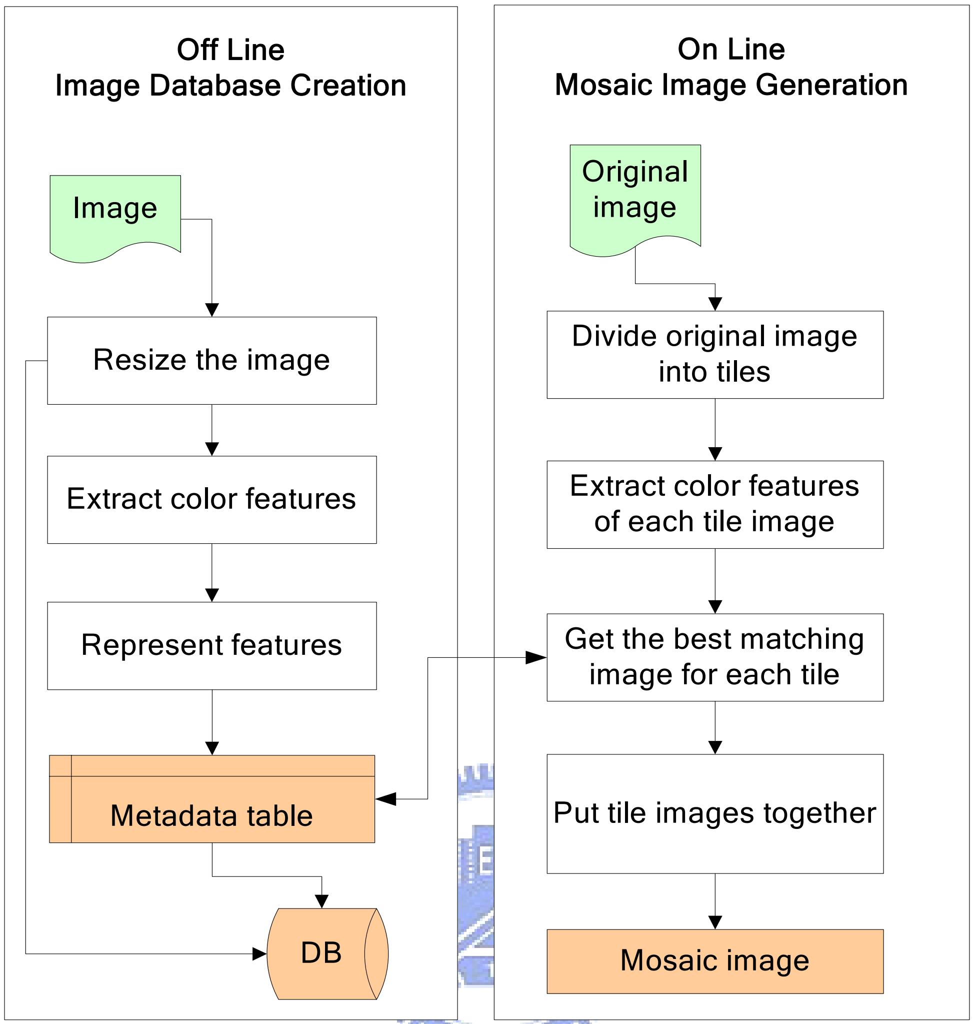


Figure 1.3 A flowchart of adopted mosaic image creation method [17].

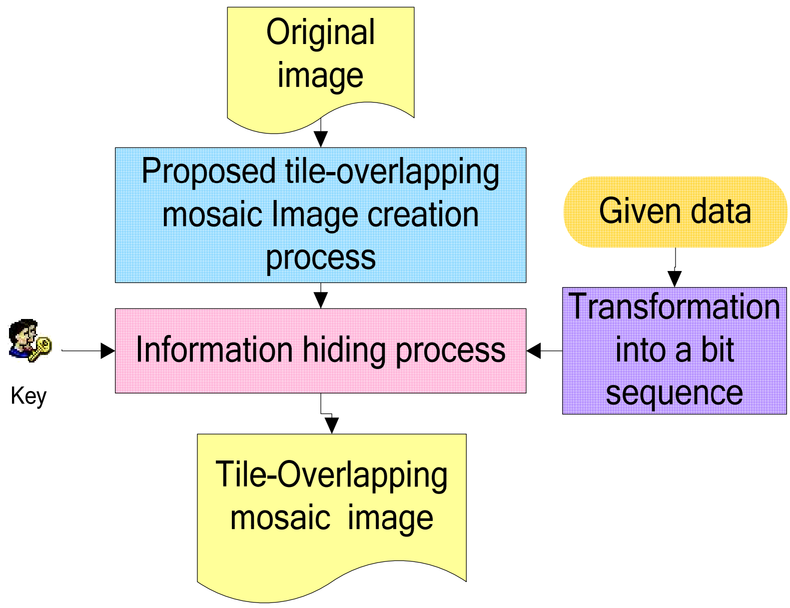


Figure 1.4 Proposed process of data hiding in tile-overlapping mosaic images.

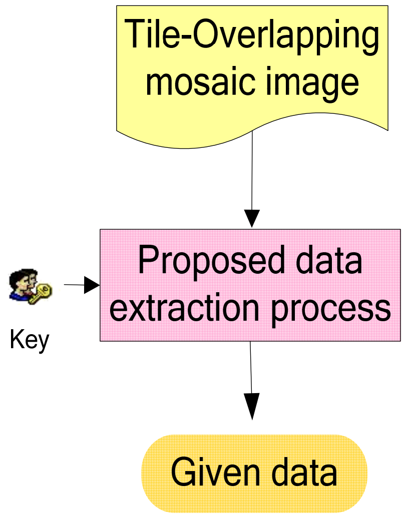


Figure 1.5 Proposed process of data extraction from overlapping mosaic images.

1.2.6 Brief Description of Proposed Method for Creation of Variable-Sized Mosaic Images and Information Hiding in Them

The process of data hiding in variable-sized images is illustrated in Figure 1.6. The data extraction process is an inverse version of the data hiding process as shown in Figure 1.7. We achieve the purpose of data hiding by changing the size of tile images in variable-sized mosaic images. For example, we use small blocks whose size is 16×16 pixels to represent bit 0 and big blocks whose size is 32×32 pixels to represent bit 1. Detailed descriptions of the proposed methods shown in these two flowcharts will be given in Chapter 5.

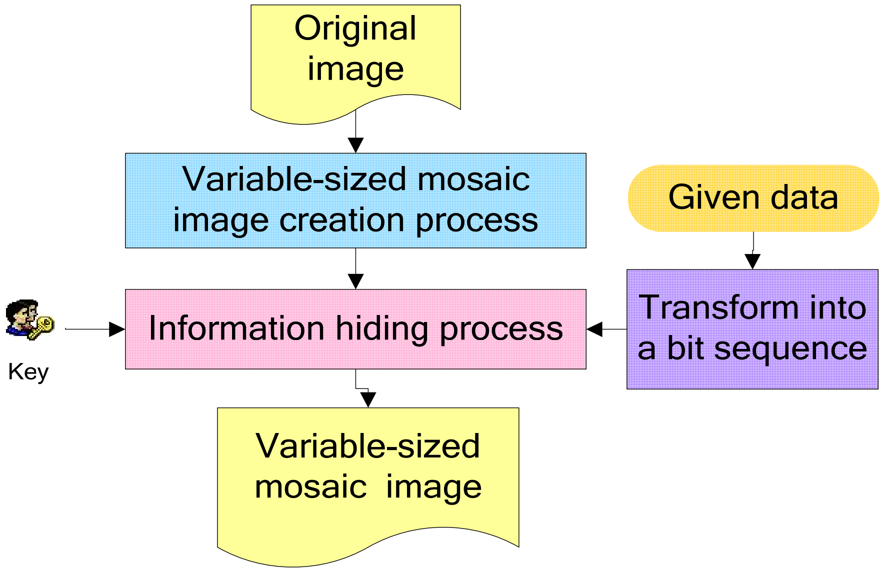


Figure 1.6 Proposed process of data hiding in variable-sized mosaic images.

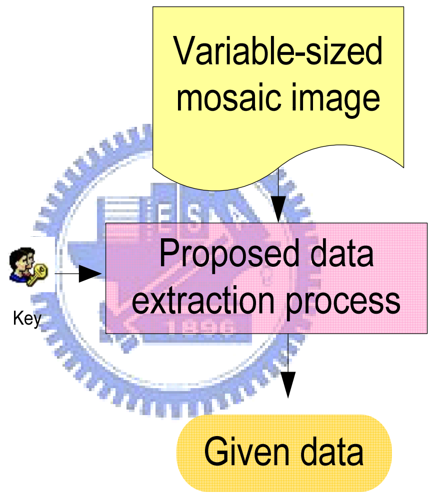


Figure 1.7 Proposed process of data extraction from variable-sized mosaic images.

1.3 Contributions

In this study, several contributions have been made, which are described in the following.

1. A method to create irregular-hexagonal-tiled images is proposed.
2. A method to hide information into irregular-hexagonal-tiled images by modifying locations of two vertices and inner colors of hexagonal tiles is proposed.

3. Methods to embed secret messages and watermarks simultaneously into the hexagonal tiles in irregular-hexagonal-tiled images are proposed.
4. A method to extract information from irregular-hexagonal-tiled images by detecting locations of two vertices and inner colors of hexagonal tiles is proposed.
5. A method to generate tile-overlapping mosaic images is proposed.
6. A method to hide information into tile-overlapping mosaic images by changing the overlapping pixels of adjacent tile images is proposed.
7. A method to embed secret messages and watermarks simultaneously into the adjacent tile images in the tile-overlapping mosaic images is proposed.
8. A method to extract information from tile-overlapping mosaic images by detecting the degree of overlapping between adjacent tile images is proposed.
9. A method to generate variable-sized mosaic images is proposed.
10. A method to hide information into variable-sized mosaic images by modifying the sizes of tile images is proposed.
11. A method to extract information from variable-sized mosaic images by detecting the sizes of the tile images is proposed.

1.4 Thesis Organization

The remainder of this thesis is organized as follows. In Chapter 2, we review related works. In Chapter 3, the proposed methods for creation of irregular-hexagonal-tiled images, information embedding, and information extraction in irregular-hexagonal-tiled images are described. In Chapter 4, the proposed methods for creation of tile image database and tile-overlapping mosaic images, information embedding, and information extraction in tile-overlapping mosaic images are described. In Chapter 5, we describe the proposed methods for creation of variable-sized mosaic images, information embedding, and information extraction in variable-sized mosaic images. Conclusions of our works as well as discussions on future works are included in Chapter 6.

Chapter 2
Review of Related Works

2.1 Previous Studies on Non-photorealistic Rendering

Non-photorealistic rendering (NPR) is a new and developing domain in computer graphics in recent years. It can express more esthetic arts than traditional photorealistic rendering. Using computers to imitate skills of painters and painting styles, we can conduct painting and obtain results which seem to be painted by famous painters, and the working time is short. How to imitate and study painting skills by computers are the major goals of NPR. Most investigations on NPR concentrate on occidental art paintings. Only a few studies on Chinese painting styles are found in the NPR domain.

Guo, et al. [1] presented an approach to generating paintings on photographic images with the style encoded by example paintings and adopted representative brushes extracted from the example paintings as the painting primitives. Figure 2.1 shows the used brushes. An experimental result is shown in Figure 2.2. Their method can be divided into the following components: (1) brush library construction; (2) region segmentation; (3) grounding layer synthesis; (4) direction field construction; (5) brush painting; and (6) fusion with images.

Chen [2] presented an approach to automatic generation of pencil sketching with the effects of paper texture. An experimental result is shown in Figure 2.3. His method can be described as follows:

(1) histogram-based image subdivision into four layers (bright, grey, darker, darkest);

(2) revised LIC (Line Integral Convolution) for pencil stroke synthesis on each layer, except for the bright layer;

(3) center-off filtering for silhouette generation;

(4) silhouette enhancement;

(5) fusion of sketching strokes in different layers, silhouettes, and enhanced parts, and paper texture.

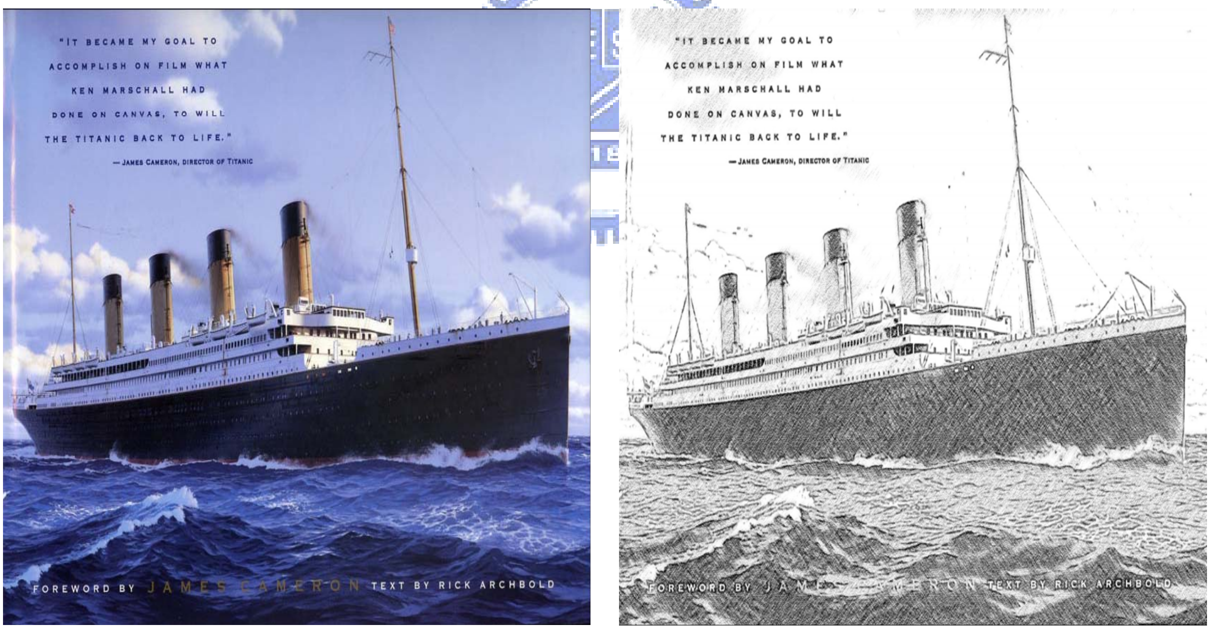
Baxter, et al. [3] presented a painting system with an intuitive haptic interface, which serves as a "semi-automatic" platform for users to create paintings interactively with computer systems. This framework allows artists to choose proper brushes from a wide selection, and also allows artists to mix and create an almost unlimited number of colors through a simple, unified interface as shown in Figure 2.5. Figure 2.4 shows some generated examples of strokes. Some artworks created using this system are shown in Figure 2.6. We show other experimental results in Figure 2.7. Figure 2.7 (a) is a watercolor image created by real-time simulation of a watery paint algorithm from Laerhoven and Reeth [4]. Figure 2.7 (b) is an image created from Hertzmann [5]. Figure 2.7 (c) is a computer-generated watercolor from [6]. Figure 2.7 (d) is an image created from Chen [7].

(a) (b)

Figure 2.1 The brushes selection process. (a) An input image: Olive Grove by Van Gogh. (b) Brushes selected from Van Gogh's Olive Grove.

(a) (b)

Figure 2.2 An experimental result. (a) An original image. (b) An image created from Guo, et al. [1].



(a) (b)

Figure 2.3 An experimental result. (a) An original image. (b) An image created from Chen [2].

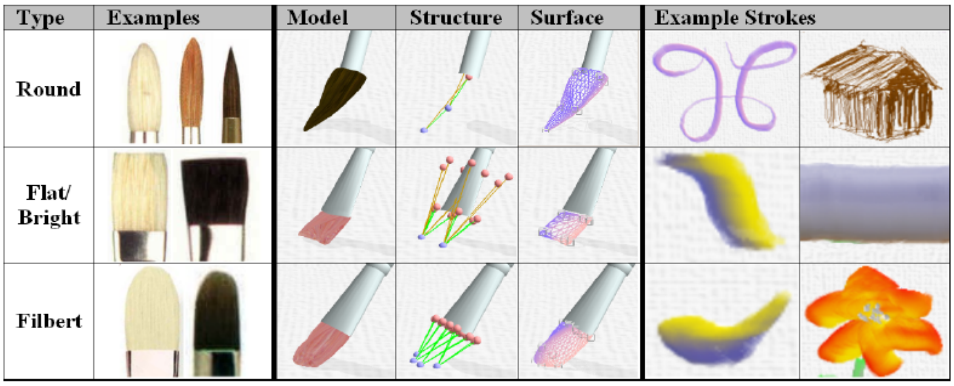
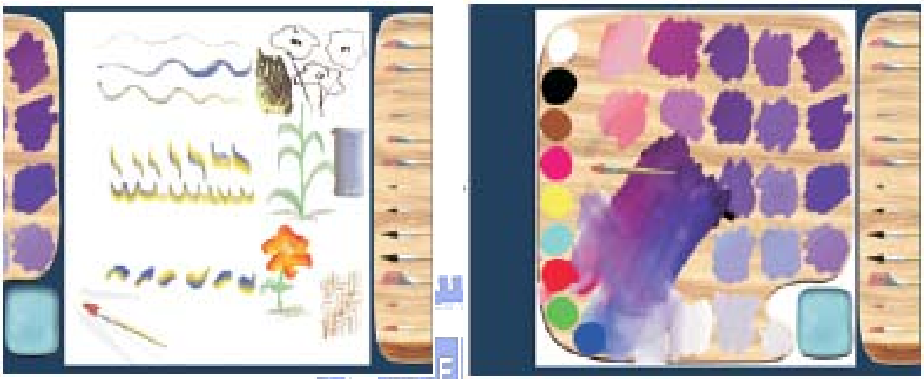


Figure 2.4 Illustration of real brushes, model for each, and example strokes generated with each [3].



(a) (b)

Figure 2.5 Graphic user interface [3]. (a) The virtual canvas with the brush rack and a part of the palette. (b) The brush rack and the palette for color mixing.

(a) (b)

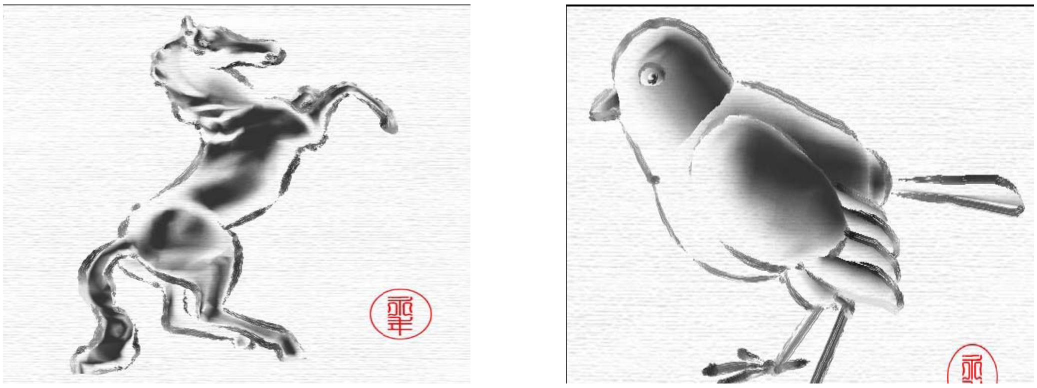
Figure 2.6 The artworks created using the system from [3]. (a) A painting by Rebecca Holmberg. (b) A painting by Lauren Adams.

(a)

(b)

(c)

Figure 2.7 Samples of computer-generator art images. (a) An image created from Laerhoven and Reeth [4]. (b) An image created from Hertzmann [5]. (c) A computer-generator watercolor from [6]. (d) An image created from Chen [7].



(d)

Figure 2.7 Samples of computer-generator art images. (a) An image created from Laerhoven and Reeth [4]. (b) An image created from Hertzmann [5]. (c) A computer-generator watercolor from [6]. (d) An image created from Chen [7]. (continued)

2.2 Previous Studies on Mosaic Images

Mosaic images are surface decorations composed of numerous small tiles, which are often of similar shapes or sizes, but in different colors. Tile mosaics appeared in Greek and Roman times over 2000 years ago, and are still widely used today. Creation of them is a new research topic in recent years.

Kojima, et al. [8] proposed a top-down approach that first generates a mosaic based on global features such as image gradations, and then incorporates local features into the underlying partition based on the global features. More specifically, they first constructed a quadrilateral mosaic using the global features, and then incorporated local features such as object silhouettes specified by users into the existing global mosaic by referring to the dual network of the mosaic partition. They proposed an effective algorithm organized in two phases as shown in Figure 2.8. Figure 2.9 is one of their experimental results.

Haeberli [9] used voronoi diagrams, placing the sites at random and filling each region with a color sampled from the underlying image. Figure 2.10 is an experimental result. Obviously, the effects of edge features are not very good. Hausner [10] proposed a method to create tile mosaic images by utilizing centroidal voronoi diagrams, as shown in Figure 2.11. In Hausner [10], the method proposed by Hoff [11] is extended to draw a voronoi diagram efficiently, and Lloyd's algorithm [12] was utilized to produce centroidal voronoi diagrams by moving each seed to the centroid of its voronoi region.

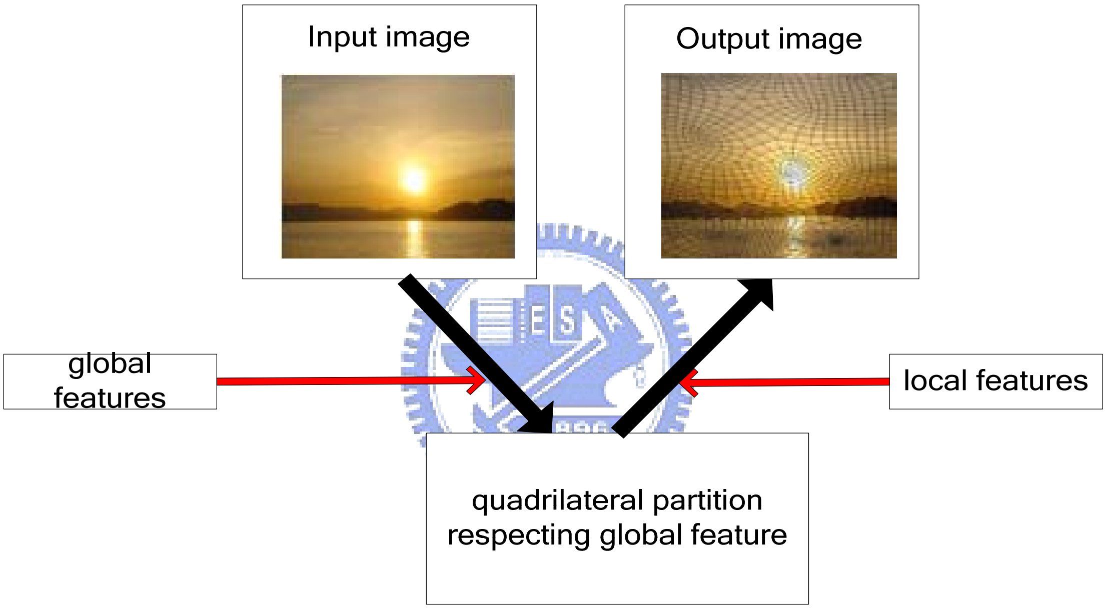


Figure 2.8 Steps in the proposed method from Kojima, et al. [8].

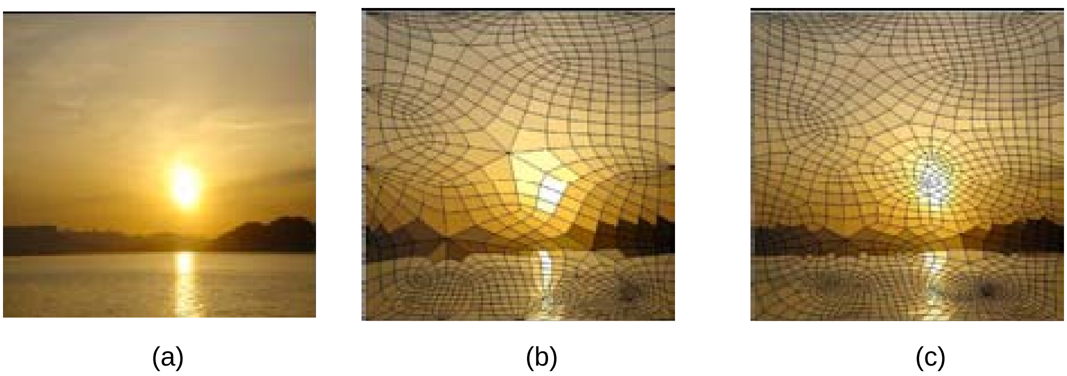


Figure 2.9 Experimental results from Kojima, et al. [8]. (a) An original image. (b) A mosaic image only with global features. (c) A mosaic image with both global and local features.

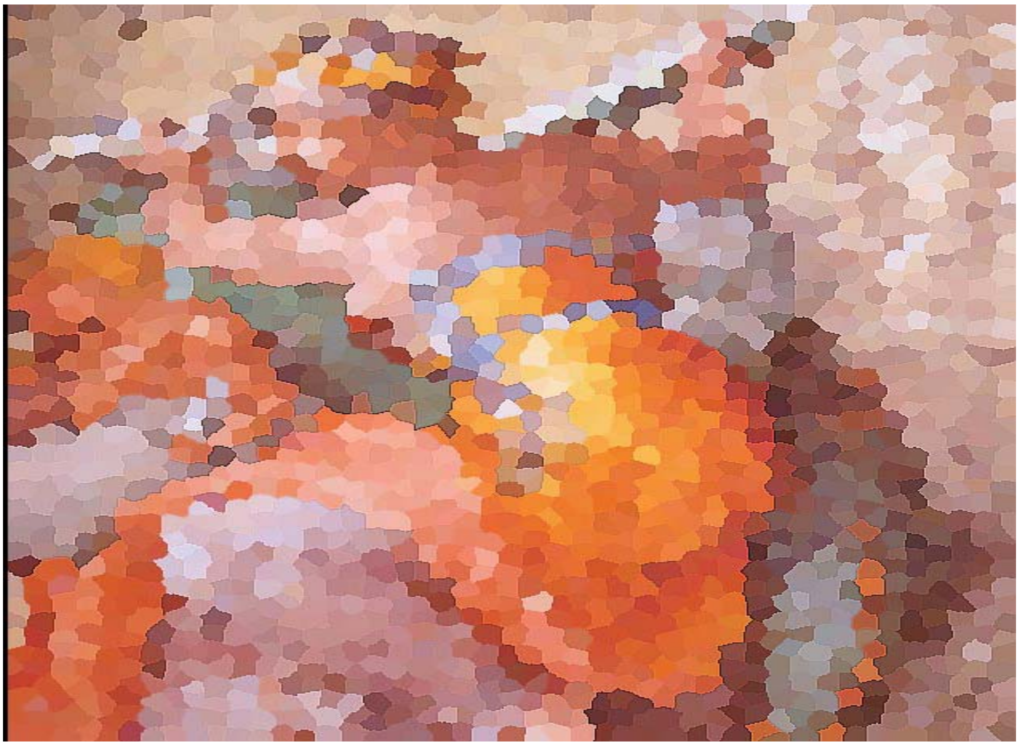


Figure 2.10 An experimental result by using Haeberli’s method [9].

Figure 2.11 An image created from Hausner [10].

2.3 Previous Studies on Information Hiding Techniques

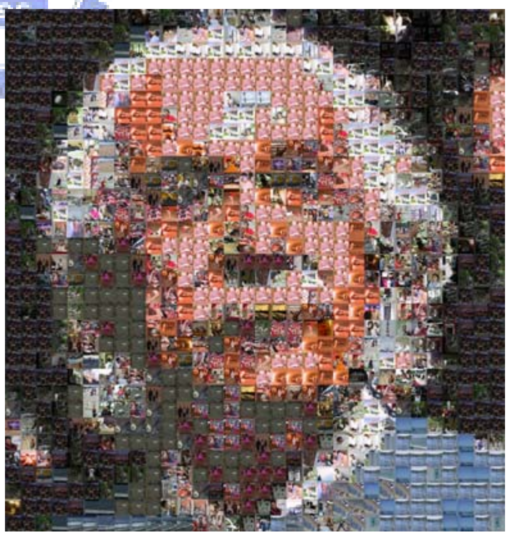
Many information hiding techniques have been proposed to embed data into a given media for various purposes. Information hiding in images mostly aims at taking the advantage of the weaknesses of the human visual system, for example, by changing the least significant bits of the pixels of a cover image to embed information [13]. The information embedded in an image can be used to protect the copyright of the image, verify the authenticity of the image, convey a secret message, and so on.

Researches on this topic can be classified into three approaches, namely, the spatial-domain approach, the frequency-domain approach, and the combination of them [14]. Ni, et al. [15] presented a novel reversible data hiding algorithm in the spatial domain by utilizing the zero or the minimum point of the histogram and slightly modified the pixel values to embed data. Cheng and Tsai [16] proposed a DCT-based method for embedding an invisible watermark by adjusting the magnitude relation of certain DCT coefficient pairs in the frequency domain. No matter what domains they belong to, most of these researches are based on pixel-wise or block-wise operations. Generally speaking, information hiding in the frequency domain is more robust than that in the spatial domain.

2.4 Previous Studies on Information Hiding in Art Images

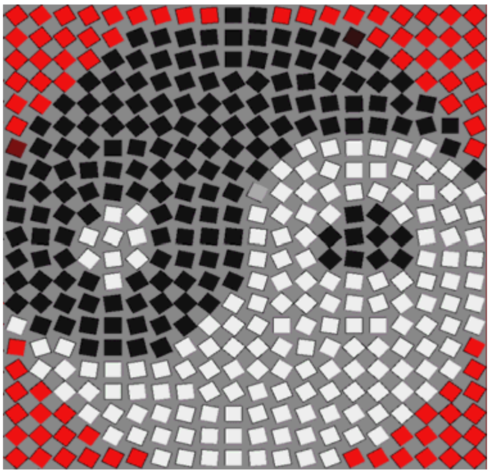
Lin [17] proposed two methods to hide information in image mosaics. One is to manipulate the four borders of tile images. The other is to modify the histogram of tile images. Hung [18] proposed two methods to hide information in art images. One is to embed data in the tile mosaic image by modifying the orientations, sizes, and textures of tile images. The other is to embed data in the stained glass image by cracking glasses slightly. Hsu [20] proposed three methods to hide information in art images. One is to embed data in digital puzzle images by modifying the orientations, sizes, and angles of the puzzle image. Another is to embed data in the pointillistic image by varying the RGB values of each color dot of the pointillistic image. The other is to embed data in the circular-dotted image by modifying the drawing order of the circular dots of the circular-dotted image. Some image mosaics created by Lin [17] are presented in Figure 2.12. Some tile mosaic images and stained glass images created by Hung [18] are shown in Figure 2.13. Some art images created by Hsu [20] are shown in Figure 2.14.

(a)



(b)

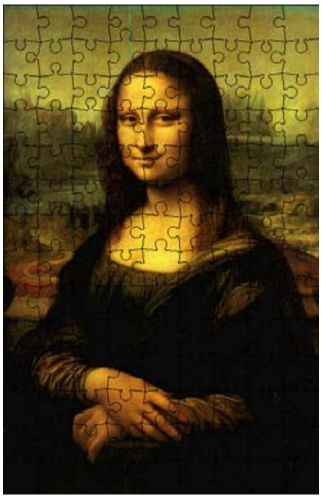
Figure 2.12 Image mosaics created by Lin [17]. (a) A mosaic image of Lena. (b) A mosaic image of Albert Einstein.



(a)

(b)

Figure 2.13 Art images created by Hung [18]. (a) A tile mosaic image. (b) A stained glass image.



(b)

(c)

(a)

Figure 2.14 Art images created by Hsu [20]. (a) A digital puzzle image. (b) A digital pointillistic image. (c) A digital circular-dotted image.

Chapter 3
Creation of Irregular-Hexagonal-Tiled Image for Information Hiding

3.1 Overview of Proposed Method

Hsu [20] proposed a method to create a pointillistic image and embed data in it by varying the RGB values of each color dot in the pointillistic image. They used small circles to fill the image to create the effect of pointillism. The idea of the proposed method to be described subsequently comes from this study.

In geometry, there are only triangles, squares, and hexagons that can be repeated and combined closely to one another and do not produce holes or overlapping areas. In these shapes, a hexagon has the largest number of vertices. So, we decide to utilize a hexagonal tile to be the basic unit when we create an art image. We found that we can implement information hiding works by modifying the locations of pairs of two specific vertices and changing the inner colors of the hexagons. Because of the vertex location modifications, the hexagonal shape appears to be irregular. So, we name the resulting art image an *irregular-hexagonal-tiled image*. We will describe the image creation and the information hiding processes for such images in the following sections.

3.2 Proposed Irregular-Hexagonal-Tiled Image Creation Process

3.2.1 Idea of Image Creation Process

Because hexagons can be combined closely to one another with no overlapping areas and because the number of their vertices is the largest among the above-mentioned three shapes, we decided to use hexagonal tiles to create an art image, as mentioned previously. But we found that if all hexagonal tiles are uniform in shape, the created image will be too dull. We also found that a vertex is used simultaneously by every three neighboring hexagons. An illustration is shown in Figure 3.1, in which $vertex_4$ is co-used by $hexagon_B$, $hexagon_C$, and $hexagon_E$, and $vertex_5$ is co-used by $hexagon_A$, $hexagon_B$, and $hexagon_C$. So, we may modify the locations of every pair of such two specific vertices of the combined hexagonal tiles to create more vivid effect in the resulting image. An illustration of a hexagonal shape with vertex numbering is shown in Figure 3.2.

In the proposed vertex position modification, with Figure 3.2 as an illustration, we just modify the y coordinate of $vertex_4$, and the x coordinate of $vertex_5$. Figure 3.3 illustrates a result after modifying these two vertices in $hexagon_B$.

A flowchart of the process of creating irregular-hexagonal-tiled images is shown in Figure 3.4. The first step is to prepare two random arrays. The second is to modify the locations of two specific vertices of the hexagons corresponding to the random array, respectively. Third, we fill the inner region of the hexagonal tiles with the colors of the center of the original hexagon. Finally, we draw a black border for each tile. The detail of the creation process will be described in the next section.

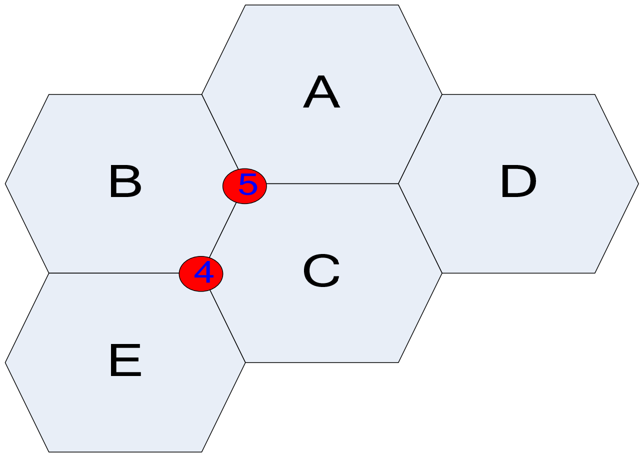


Figure 3.1 The combined hexagonal-tiled image.

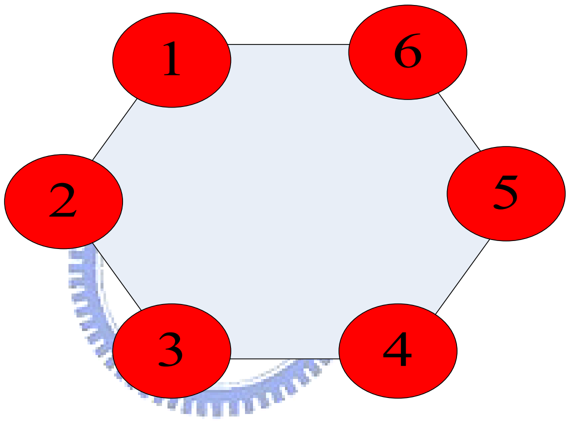


Figure 3.2 $Vertex_4$ and $vertex_5$ will be modified.

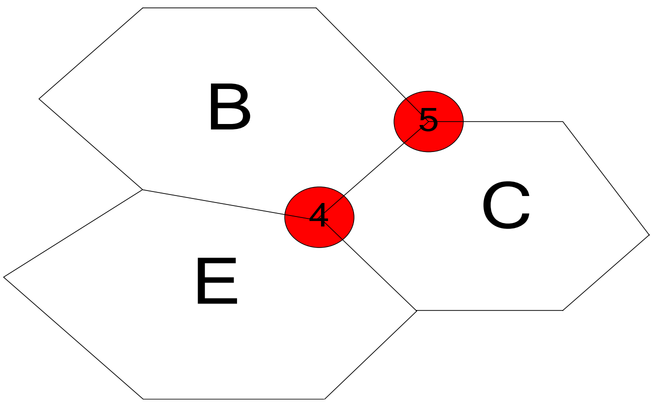


Figure 3.3 The combined hexagonal-tiled image after modifying $vertex_4$ and $vertex_5$.

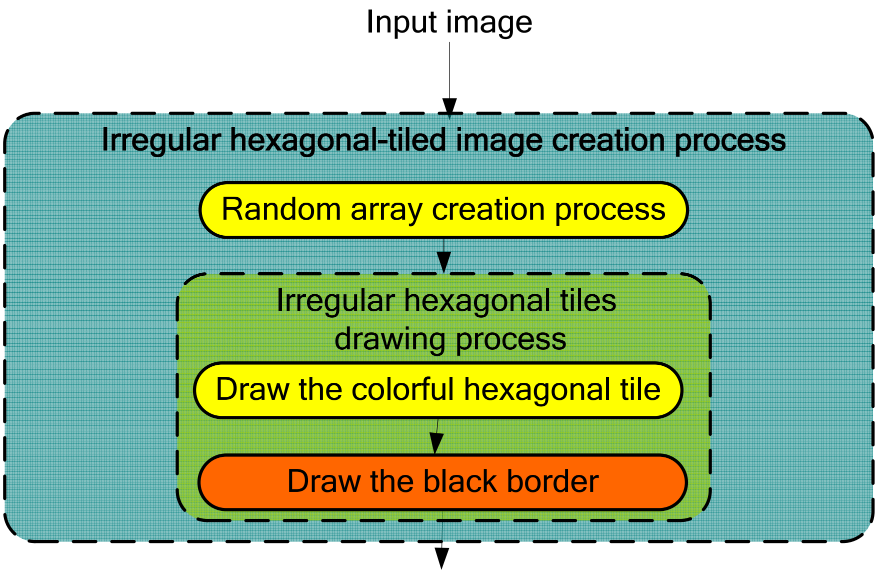


Figure 3.4 A flowchart of the irregular-hexagonal-tiled image creation process.

3.2.2 Detail of Image Creation Process

The default width of the hexagonal tile is 6 pixels. The user can adjust the size, and input a desired value while executing the program. The detailed process is described as an algorithm as follows.

Algorithm 3.1: irregular-hexagonal-tiled image creation process.

Input: an image *I* and the width *w* of a hexagon.

Output: an irregular-hexagonal-tiled image *I'*.

Steps:

Step 1. Figure out how many hexagonal tiles will be drawn in an irregular-hexagonal-tiled image by utilizing the input width *w* and the width of the original image.

Step 2. Create two random arrays RA_1 and RA_2.

Step 3. Modify the locations of the above-mentioned two specific vertices using RA_1 and RA_2, respectively, like the example illustrated in Figure 3.2 and Figure

3.3.

Step 4. Draw the resulting hexagonal tile at the upper leftmost corner of the output image *I*′.

Step 5. Conduct the same operations of Steps 1 through 3 to draw hexagonal tiles in a raster scanning manner.

In Step 2, we must create RA_1 and RA_2. We use Algorithm 3.2 below to describe the creation process.

Also, in Step 4, drawing of a hexagonal tile is divided into two smaller steps as follows.

(1) Fill the inner region of the hexagonal tile with the colors of the center of the original hexagonal shape.

(2) Draw a black border around the hexagonal tile.

Algorithm 3.2: create a random array.

Input: the number *N* of hexagonal tiles which will be drawn.

Output: a random array *R*.

Step 1. Set the array whose size is equal to *N*.

Step 2. Set each of the value of the array to be a random integer ranging from −2 to +2, using a suitable random number generator.

3.2.3 Experimental Results and Discussions

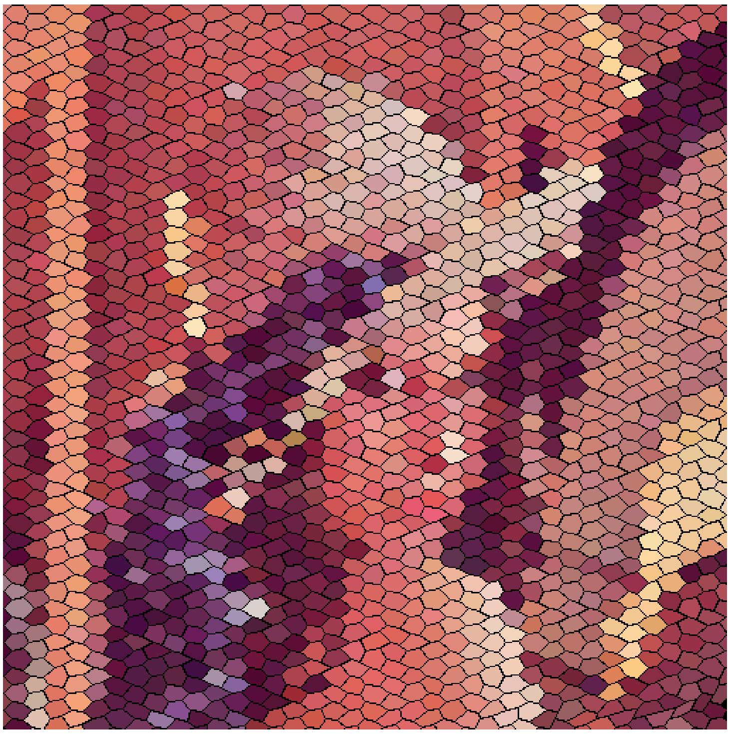
Figure 3.5(a) is an input image; Figure 3.5(b) is the corresponding irregular-hexagonal-tiled image created by applying the above irregular-hexagonal-tiled image creation process. Here, the input width of the hexagonal tile is 6. Figure 3.5(c) is the irregular-hexagonal-tiled image created from

Figure 3.5(a), but with the input width of the hexagonal tile being 8.

(a)

(b)

Figure 3.5 Experimental results. (a) An original image. (b) An irregular-hexagonal-tiled image with width＝6. (c) An irregular-hexagonal-tiled image with width＝8.



(c)

Figure 3.5 Experimental results. (a) An original image. (b) An irregular-hexagonal-tiled image with width = 6. (c) An irregular-hexagonal-tiled image with width = 8. (continued)

3.3 Proposed Method for Data Hiding in Irregular-Hexagonal-tiled Images

3.3.1 Concept of Proposed Method

The main concept of the proposed method for data hiding in an irregular-hexagonal-tiled image is to adjust the locations of two specific vertices and modify the inner colors of the hexagonal tiles. We can hide thirteen bits into each hexagonal tile by these two techniques. First, we divide the bit stream sequence of a given secret message into several groups, each of which has thirteen bits. An example is shown in Table 3.1. Second, we take the first two bits (part1) and check a "matching table" shown in Table 3.2 to get the variation of the *y* coordinate of $vertex_4$ of the hexagonal shape to be drawn. Repeating these operations similarly, we can get the variation of the *x* coordinate of $vertex_5$. Then, we divide the remaining 9 bits (part3 to part5) into three parts, and transform them into decimal numbers. The decimal values are taken as the variations of the RGB values of the inner color of the hexagonal tile to be drawn, respectively. In short, we implement the desired information hiding work by utilizing these two techniques. The details will be stated clearly in Section 3.3.3.

Table 3.1 Components of hiding bits of a bit stream sequence of a given message.

12	11	10	9	8	7	6	5	4	3	2	1	0	bits order
B			G			R			$vertex_5$		$vertex_4$		modified part
part5			part4			part3			part2		part1		part number

Table 3.2 A matching table for specifying vertex position variations.

Hiding bits	Variation
00	-2
01	-1
10	+1
11	+2

3.3.2 Data Combination and Disarrangement Processes

We assume, as done in the information paradigm that the secret information may be extracted by people who know the algorithm, so it is necessary to utilize a secret key to disorder the secret information before embedding it. The details of the data combination and disarrangement processes are described as an algorithm as follows.

Algorithm 3.3: data combination and disarrangement processes.

Input: a bit sequence of a secret message Mes_i, a bit sequence of a watermark $Water_i$, and a bit sequence of a secret key K_i.

Output: a randomized bit sequence of the combination of the inputs Mes_i and $Water_i$.

Steps:

Step 1. Create an empty array, *Data*, whose size is equal to that of Mes_i plus $Water_i$.

Step 2. Arrange the elements of Mes_i into *Data* in order and append the elements of $Water_i$ into *Data* in order at the end of Mes_i.

Step 3. Use the secret key K_i to create a random binary array, *Key*, whose size is equal to that of *Data*.

Step 4. Apply the exclusive-OR operator to *Data* and *Key* bit by bit to obtain a randomized bit sequence, $DData_i$, combining the secret message and the watermark.

3.3.3 Data Hiding Process

A flowchart of the data hiding process is shown in Figure 3.6. First, we derive a randomized $Data_i$, denoted as $DData_i$, from the inputs Mes_i and $Water_i$, using Algorithm 3.3. Then we divide $DData_i$ into several string parts each of which has a size of thirteen, and divide each of them further into five parts. An example is shown in Table 3.1. The first and the second parts specify the *y* and *x* coordinate variations of $vertex_4$ and $vertex_5$ of the hexagonal tile to be drawn, respectively. The other three parts are used as the augmentative values of the RGB values of the center colors of the hexagonal tiles in the original image. Finally, we apply the proposed irregular-hexagonal-tiled image creation process described previously. Then we can get a stego-irregular-hexagonal-tiled image. The detail of the data hiding process is described as an algorithm below.

Algorithm 3.4: data hiding in an irregular-hexagonal-tiled image.

Input: an image *I*, a secret message *Mes*, a watermark *Water*, and a secret key *K*.

Output: a stego-irregular-hexagonal-tiled image *I'*.

Steps:

Step 1. If the RGB values of any pixel of *I* are smaller than (8, 8, 8), respectively, we replace them with the RGB values (8, 8, 8). Set the RGB values of each pixel in *I* to be multiples of eight. That is, compute

new value *r* (denoted as *Nvr*) = (original *r* value / 8) × 8;

new value *g* (denoted as *Nvg*)= (original *g* value / 8) × 8;

new value *b* (denoted as *Nvb*)= (original *b* value / 8) × 8.

Step 2. Convert the secret message size into a bit stream sequence, and then use Algorithm 3.5 to embed it in the first hexagonal tile.

Step 3. Convert the watermark size into a bit stream sequence, and then use Algorithm 3.5 to embed it in the second hexagonal tile.

Step 4. Convert *Mes* and *Water* into bit sequences Mes_i and $Water_i$, respectively.

Step 5. Use the secret key *K*, Mes_i, and $Water_i$ to derive a randomized bit stream sequence *S* by applying Algorithm 3.3.

Step 6. Divide S into several substrings, each of which has a size of thirteen.

Step 7. Use Algorithm 3.5 below to construct a stego-hexagonal tile in a raster scanning manner until all substrings are handled.

Algorithm 3.5: data hiding in a hexagonal tile.

Input: a hexagonal tile T and a binary substring s whose size is thirteen.

Output: a stego-hexagonal-tile T'.

Steps:

Step 1. Take the fist part of s to check the matching table which is shown in Table 3.2, and compute the new y coordinate of its vertex_4 as the found variation in the table plus the original y coordinate of the vertex in T.

Step 2. Take the second part of s to check the matching table, and compute the new x coordinate of its vertex_5 as the variation found in the table plus the original x coordinate of the vertex in T.

Step 3. Transform the third part of s into a decimal integer, denoted as *addR*, and set the final value r equal to *addR* plus *Nvr* mentioned previously.

Step 4. Transform the fourth part of s into a decimal integer, denoted as *addG*, and set the final value g equal to *addG* plus *Nvg*.

Step 5. Transform the fifth part of s into a decimal integer, denoted as *addB*, and set the final value b equal to *addB* plus *Nvb*.

Step 6. Draw the hexagonal tile with a black border.

3.3.4 Data Extraction Process

The main concept of the data extraction process is to figure out the variations of the locations of every two specific vertices and the inner colors of the hexagonal tiles, and compose the data to recover the originally embedded secret message in a given stego-image.

In $vertex_4$, we only modified the *y* coordinate in the data embedding process and we know the original *y* coordinate. So, we just sequentially check the possible locations of $vertex_4$, and then check the matching table shown in Table 3.2 to get the hidden bits. In $vertex_5$, the situation is almost the same as in $vertex_4$. The only difference is that the modified coordinate of $vertex_5$ is the *x* coordinate. In this way, we can get four bits from $vertex_4$ and $vertex_5$. Then we proceed to get the RGB values of the inner colors of the hexagonal tiles and acquire the remainders of the RGB values by dividing them by eight, respectively. Finally, we convert in order the three remainders into a bit sequence whose number is 9. The data extraction process is completed after concatenating all extracted bits in order. The process is described as an algorithm below.

Algorithm 3.6: data extraction from an irregular-hexagonal-tiled image.

Input: a stego-irregular-hexagonal-tiled image I'.

Output: a randomized bit stream sequence, the message size, and the watermark size.

Steps:

Step 1. Find the secret message size by the following way.

1.1. Use Algorithm 3.7 to extract a bit stream sequence from the first hexagonal tile shown in Figure 3.7.

1.2. Convert the bit stream sequence into a decimal value.

1.3. Take the decimal value as the desired secret message size.

Step 2. Find the watermark size by the following way.

2.1. Use Algorithm 3.7 to extract a bit stream sequence from the second hexagonal tile shown in Figure 3.7.

2.2. Convert the bit stream sequence into a decimal value.

2.3. Take the decimal value as the desired watermark size.

Step 3. Use Algorithm 3.7 to extract a bit stream sequence from each of the hexagonal tiles which are marked by the purple arrows shown in Figure 3.7 in order.

Step 4. After all the hexagonal tiles are processed, compute the desired randomized bit stream sequence by concatenating all the sequences obtained previously in order.

Algorithm 3.7: data extraction from an irregular-hexagonal tile.

Input: an irregular-hexagonal tile *T*.

Output: a bit stream sequence whose size is thirteen.

Steps:

Step 1. Find the new *y* coordinate of $vertex_4$ of *T*.

Step 2. Subtract the original *y* coordinate from the new *y* coordinate derived in Step 1 to get an integer.

Step 3. Take the integer to check the matching table to get two bits.

Step 4. Find the new x coordinate of $vertex_5$ of *T*.

Step 5. Subtract the original *x* coordinate from the new *x* coordinate derived in Step 4 to get an integer.

Step 6. Take the integer to check the matching table to get two message bits.

Step 7. Take the RGB values from the center of *T*.

Step 8. Calculate the remainders of the RGB values by dividing the RGB values by eight, respectively.

Step 9. Convert the three values obtained in the last step into a bit stream sequence with nine bits.

Step 10. Combine the thirteen bits in order to obtain the desired secret bit streams.

3.3.5 Data Recovery and Separation Processes

The data recovery and separation processes are the inverse version of the data combination and disarrangement processes which are proposed in Section 3.3.2. They are described as an algorithm below.

Algorithm 3.8: data recovery and separation processes.

Input: a randomized bit stream sequence $DData_i$, a secret key K, and a secret message size M.

Output: a secret message Mes_i and a watermark $Water_i$.

Steps:

Step 1. Use the secret key K to create a binary array, Key, whose size is equal to that of $DData_i$.

Step 2. Apply the exclusive-OR operator to $DData_i$ and Key, resulting in the original bit sequence $Data_i$ of the combination of the inputs Mes_i and $Water_i$.

Step 3. Take the first M bits from $Data_i$ as Mes_i, and the other part as $Water_i$.

3.3.6 Experimental Results and Discussions

Figure 3.8 shows some experimental results of data hiding in an irregular-hexagonal-tiled image. Figure 3.8 (a) is an irregular-hexagonal-tiled image with the secret message, "Lena 是一位瑞典女士 Lena Sjooblom 的照片," and the watermark, Figure 3.8 (c), embedded. Figure 3.8 (b) is the secret message extracted from Figure 3.8 (a) with a correct key. Figure 3.8 (d) is the watermark extracted from Figure 3.8 (a) with a correct key. Figure 3.8 (e) shows the extraction results from

Figure 3.8 (a) with a wrong key.

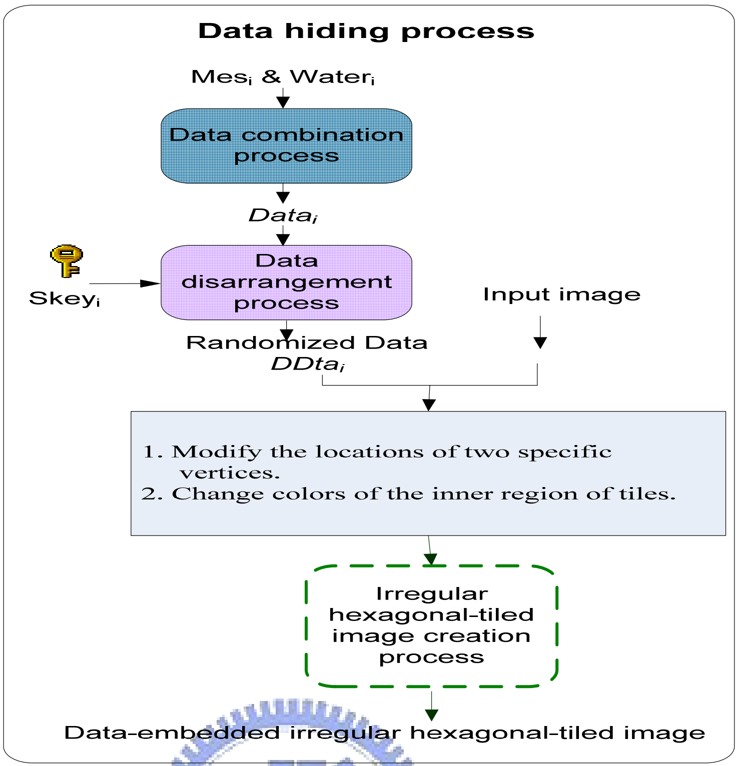


Figure 3.6 A flowchart of the data hiding process in the irregular-hexagonal-tiled image.

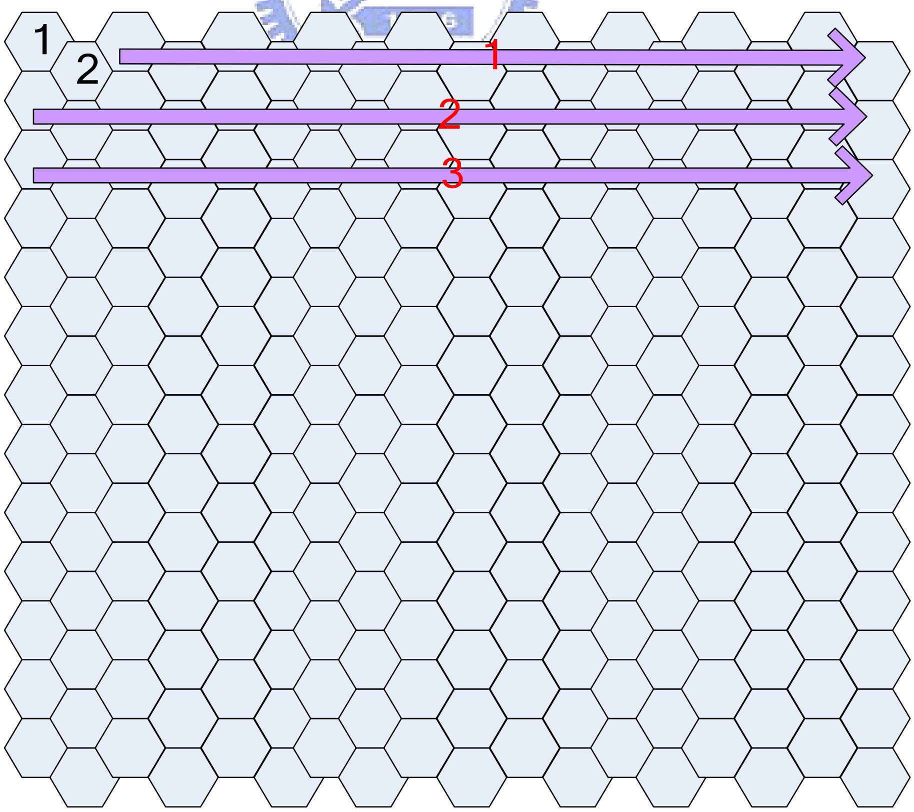
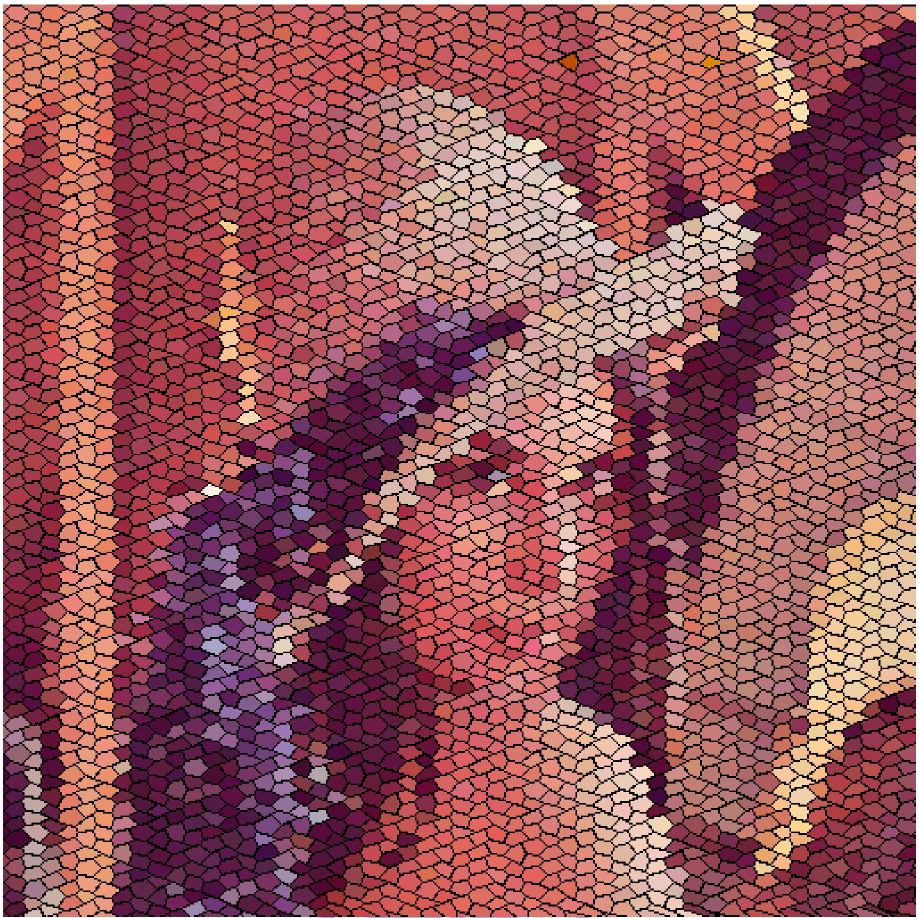
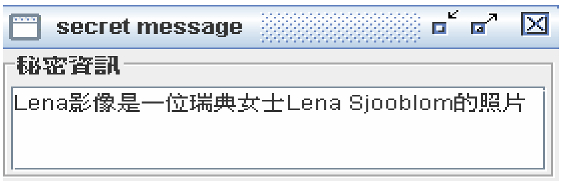


Figure 3.7 Data extraction order.

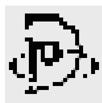


(a)

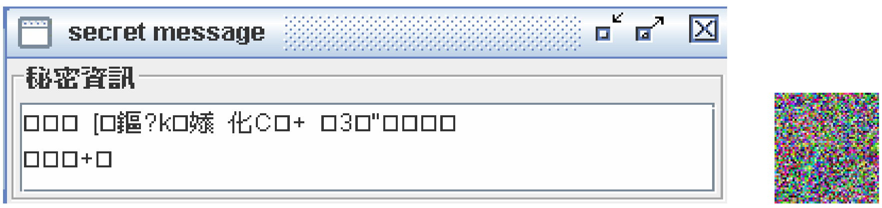


(b)

(c)



(d)



(e)

Figure 3.8 Experimental results of data hiding in an irregular-hexagonal-tiled image. (a) An irregular-hexagonal-tiled image with the secret message and watermark (c) embedded. (b) The secret message extracted from (a) with a correct key. (d) A watermark extracted from (a) with a correct key. (e) The extraction results from (a) with a wrong key.

Chapter 4
Creation of Tile-Overlapping Mosaic Images for Information Hiding

4.1 Review of Traditional Mosaic Image Creation Process

4.1.1 Mosaic Images Creation Process

A method [17] of mosaic image creation is adopted in this study and a flowchart of it is shown in Figure 4.1. The creation process can be divided into two major stages. One is construction of a tile image database and the other is generation of mosaic images. The first stage is conducted off-line, and the second on-line. A tile image database is established prior to the mosaic image generation process. Some metadata of the tile images need be built through a feature extraction process and such metadata are mainly the descriptions of the color distributions of the tile images. We will describe how to construct a tile image database in Section 4.1.2. The mosaic image generation process aims to divide an input image into numerous tiles based on a given tiling style. Additionally, a similarity measure is employed to get the best matching image from the tile image database for each tile. Finally, we compose all of the best-matching tile images together to produce a mosaic image. The detail of the process of mosaic image generation is described as an algorithm as follows.

Algorithm 4.1: mosaic image generation process.

Input: an image *I*, a tile image database *DB*, and a tiling style *S*.

Output: a mosaic image.

Steps:

Step 1. Divide *I* into tiles according to *S*.

Step 2. Get the best matching tile image from *DB* for each target tile *T* according to the following rule.

2.1. Calculate the average colors of *T*.

2.2. Represent the colors as a one-dimension feature vector V_{target}.

2.3. Get a feature vector V_{tile} from the metadata of *DB*.

2.4. Calculate the distance between V_{tile} and V_{target} according to the following formula where $|\cdot|$ means the Euclidean distance:

$$D = |V_{target} - V_{tile}|^2.$$

2.5. Find the smallest *D* after testing all V_{tile} from *DB*.

2.6. Get the best matching tile image from *DB* accordingly.

Step 3. Compose all of the tile images together according to *S* to produce a mosaic image.

4.1.2 Tile Image Database Construction

Tile image database construction is the first step for mosaic image creation and it plays an important role in the entire process. We utilize a database to store the extracted color features and this can accelerate the computation of searching the best matching tile image. We accomplish tile image database construction using the following algorithm.

Algorithm 4.2: tile image database construction.

Input: a set of images, $S = \{I_1, I_2, \ldots, \mathrm{I}_n\}$.

Output: a set of tile images, $O = \{T_1, T_2, .., T_n\}$, for use as the tile image database and an associated metadata table M.

Steps:

Step 1. Resize each I_i, $i = 1, 2, \ldots, n$, to a pre-defined tile image size, resulting in a new image T_i.

Step 2. Calculate the average color of T_i in each of the RGB channels.

Step 3. Represent the average colors as a one-dimension feature vector V_i with three elements R_i, G_i, and B_i.

Step 4. Add V_i to M.

Step 5. Save O and M in the storage as the desired output.

In this study, the pre-defined tile image size is chosen to be 32×32 pixels. After resizing an input image, we extract and represent the color features extracted from it as a vector. In the RGB color model, we use red, green, and blue as the three primary colors. A metadata table is built by combining all the feature vectors derived from Step 4.

4.1.3 Similarity Measure for Tile Matching

In the above algorithm, we see that the adopted similarity measure between a target image and a tile image from a database is based on the RGB color model. A feature vector is obtained by calculating the average color of a tile image in each of the RGB channels. In the mosaic image generation process, an image from the tile image database is considered to be the most similar to a given target image if the value of the similarity measure based on the Euclidean distance between the two feature vectors is the smallest.

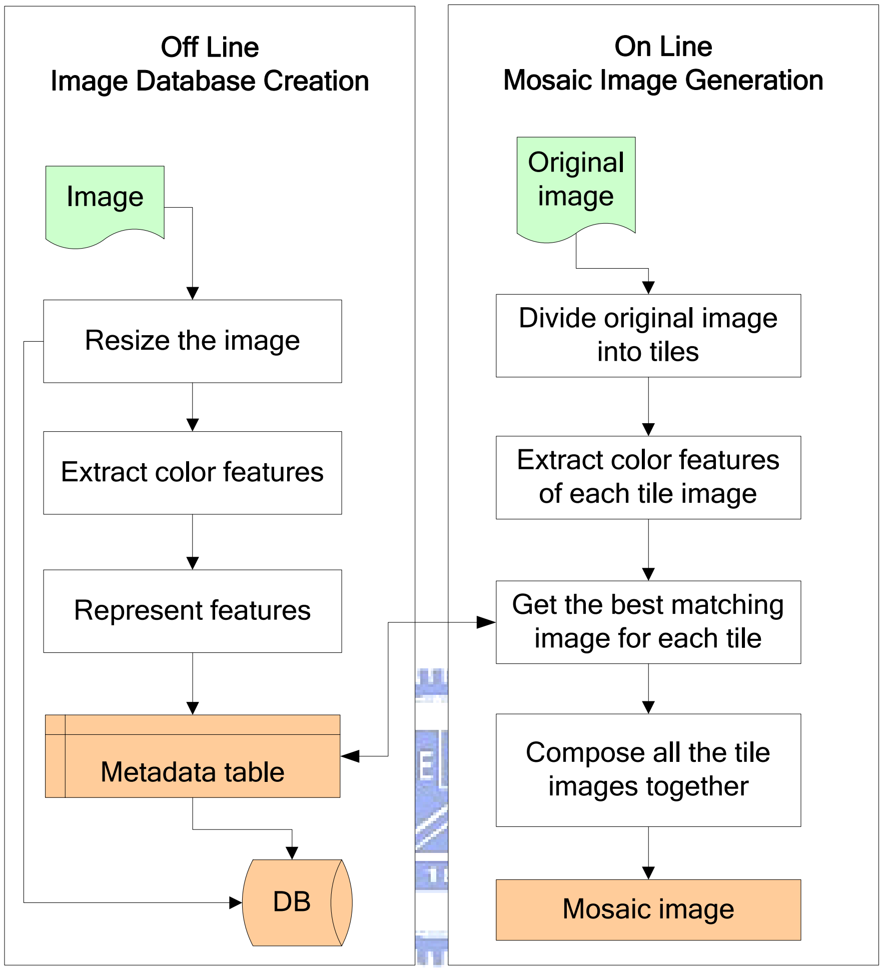


Figure 4.1 A flowchart of adopted mosaic image creation method [17].

4.2 Overview of Proposed Method

Traditional mosaic images contain numerous tile images which are of uniform sizes, and the arrangement of them is usually regular. However, we want to create new-styled mosaic images in this study by modifying the regular arrangement style of the tile images. An illustration of the proposed arrangement scheme is shown in Figure 4.2(b). Additionally, during the image creation process, we desire also to achieve the data hiding application by utilizing the arrangement scheme. We will state how to create the mosaic image and explain how we carry out the data hiding operation during the image creation process in the following sections.

4.3 Proposed Tile-Overlapping Mosaic Image Creation Process

4.3.1 Idea of Image Creation Process

Our inspiration of this topic of study comes from the creation process of the circular-dotted image proposed by Hsu and Tsai [19]. The main concept of the creation process of the circular-dotted image is to utilize the drawing order of the circular-dots in a circular-dotted image. We imitate their overlapping scheme. However, the basic unit of our 'painting' here is a tile image. The arrangement of tile images in a traditional mosaic image is shown in Figure 4.2(a) and the proposed arrangement of tile images in the proposed new-styled mosaic image is shown in Figure 4.2(b). The traditional arrangement is regular, while the proposed arrangement is irregular. In the traditional arrangement, we know in advance the location of each tile image. However, in the proposed new arrangement, we do not know the location of each tile image beforehand because we randomize the locations of each tile. The randomization is controlled by the use of a random number generator. So, the tile arrangements are unfixed in appearance, thus yielding a more vivid effect in the resulting image. However, this brings a problem. That is, due to irregular overlapping of the tiles, holes between adjacent tiles will be created and might block the data extraction process conducted later. So, how to avoid causing this hole-creation problem during the image creation process is a critical issue. A solution proposed in this study will be described later. On the other hand, the randomized tile overlapping degree is fixed to be in a specific range, taken to zero to seven pixels in this study. We utilize such tile overlapping degrees to implement the data hiding work. More specifically, a tile overlapping degree of *n* pixels is used to embed a 3-bit message data of the value *n*. For example, if the message to be embedded is $101_2 = 5_{10}$, then we let a tile image to overlap its preceding one either in the horizontal or vertical direction for 5 pixels to accomplish the embedding purpose. The image creation and data hiding processes are stated in the following.

4.3.2 Detail of Image Creation Process

In this section we show how to create a tile-overlapping mosaic image. The major steps are as follows.

(1) Construct a tile image database.

(2) Process the input image in the following order: the first column, the first row, and then the inner tiles.

(3) In the first column, draw one by one the *best-matching* tile images in such a way that the current one overlaps randomly the bottom side of the preceding one.

(4) In the first row, perform works similar to the last step but with the overlapping being on the right side of the preceding tile.

(5) Draw the inner tiles in a raster scan order in such a way that the current tile overlaps, in a random way, both the right side of the left tile and the bottom side of the upper one.

In the above process, a best-matching tile image drawn at a location is the one in the tile image database, which is most "similar" to the image part appearing at the same location (called *target image* subsequently) in the input image (called *cover image* in the sequel). Also in the last step above, the random overlappings there, as mentioned previously, might create holes, which we want to eliminate. A technique to achieve this purpose is to move the tile to be drawn toward the left or upper direction *pixel by pixel* until the hole disappears. More details of the process are described as an algorithm below.

Algorithm 4.3: creation process of tile-overlapping mosaic image.

Input: a cover image I; a tile image database DB with each image being of the size $SZ\times SZ$ with SZ being a given integer; a similarity measure SM, and a random number generator F for integers in the range of 0 through 7.

Output: a tile-overlapping mosaic image I_m for I.

Steps:

Step 1. Create the first column of I_m in the following way:

1.1. Crop the upper-leftmost $SZ\times SZ$ subimage of I and take it to be the target image Tar_{00}.

1.2. Search DB for the tile image Bmt_{00} which matches Tar_{00} the best according to the given similarity measure SM.

1.3. Draw Bmt_{00} in I_m at the same location as that of Tar_{00} with a black border.

1.4. Generate a random integer number RN in the range of 0 to 7 by F.

1.5. Crop as a target image Tar_{0j} from I an $SZ\times SZ$ image right below the preceding target image $Tar_{0(j-1)}$ but with RN-pixel overlapping.

1.6. Search DB for the tile image Bmt_{0j} which best matches Tar_{0j} according to SM.

1.7. Draw Bmt_{0j} in I_m at the same location as that of Tar_{0j} with a black border.

1.8. Repeat Steps 1.4 through 1.7 until the entire first column of I_m are processed.

Step 2. Process the first row of I_m in a similar way to Step 1 except that the overlapping is on the right side of the preceding tile image.

Step 3. Process the inner tiles of I_m in a raster scan order in the following way:

3.1. Generate by F two random integer numbers RN_1 and RN_2 ranging from 0 to 7.

3.2. Derive the position of Tar_{ij} using RN_1 and RN_2, which is to the right of the horizontally preceding target image $Tar_{(i-1)j}$ in I_m and below the vertically preceding target image $Tar_{i(j-1)}$ with an RN_1-pixel horizontal overlapping as well as an RN_2-pixel vertical overlapping.

3.3. Check by the following way if a hole like either case shown in Figure 2 is created by Tar_{ij} in the last step.

Case 1:

1a. the vertically preceding target image $Tar_{i(j-1)}$ has its upper boundary higher than that of the upper-left neighboring target image $Tar_{(i-1)(i-1)}$; and

1b. there is a gap between the upper boundary of $Tar_{(i-1)j}$ and the lower boundary of $Tar_{i(j-1)}$; and

1c. there is a gap between the right boundary of $Tar_{(i-1)(j-1)}$ and the left boundary of Tar_{ij}.

Case 2:

2a. the vertically preceding target image $Tar_{i(j-1)}$ has its upper boundary lower than that of the upper-left neighboring target image $Tar_{(i-1)(i-1)}$;

2b. there is a gap between the right boundary of $Tar_{(i-1)j}$ and the left boundary of $Tar_{i(j-1)}$;

2c. there is a gap between the lower boundary of $Tar_{(i-1)(j-1)}$ and the upper boundary *of* Tar_{ij}.

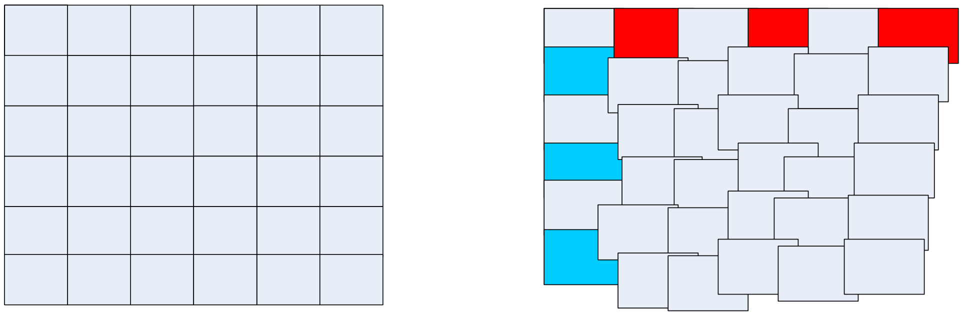
If a hole of Case 1 is created, move Tar_{ij} to the left until the hole disappears, and crop an $SZ \times SZ$ target image from I at the new position as Tar_{ij}; or if a hole of

Case 2 is created, move Tar_{ij} upward until the hole disappears, and crop an $SZ \times SZ$ target image from I at the new position as Tar_{ij}

3.4. Search DB for the tile image Bmt_{ij} which best matches Tar_{ij} according to SM.

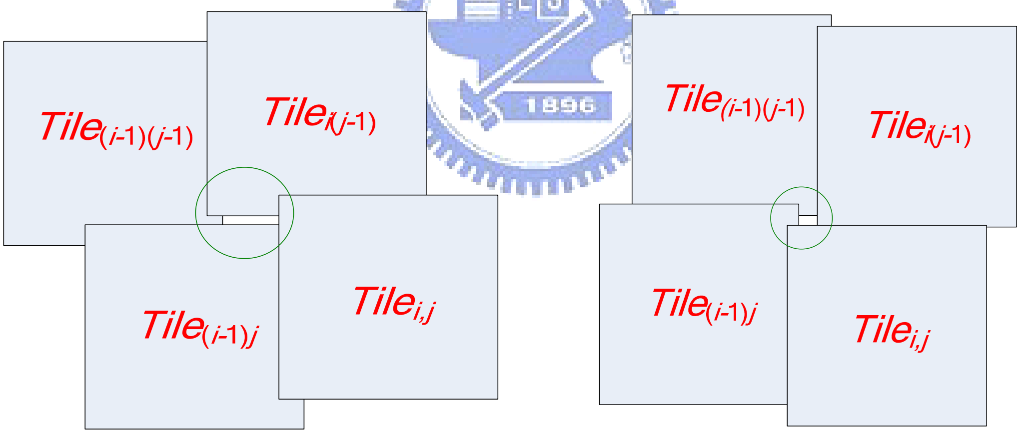
3.5. Draw Bmt_{ij} in I_m at the same location as that of Tar_{ij} with a black border.

3.6. Repeat Steps 3.1 through 3.6 until all the inner tiles of I_m are processed.



(a) (b)

Figure 4.2 Tile arrangements. (a) The arrangement of the traditional tile images. (b) The proposed arrangement of tile images.



(a) (b)

Figure 4.3 The creation process may cause a hole by the illegal arrangement of $Tile_{i,j}$. (a) Case 1. (b) Case 2.

4.3.3 Experimental Results and Discussions

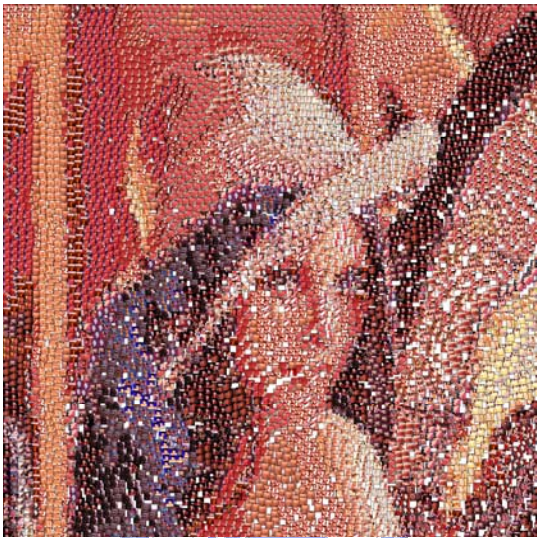
All the mosaic images of our experimental results were generated by using the tile image database with about 1900 images. The hiding capacity is about three thousand bytes. Figure 4.4(a) is an input image. Figure 4.4(b) is the resulting tile-overlapping mosaic image created from Figure 4.4(a) by applying the tile-overlapping mosaic image creation process in Section 4.3.2. Figure 4.4(c) is an image composed of several tile images of the red region in Figure 4.4(b). Figure 4.4(d) is the resulting tile-overlapping mosaic image with white holes.

(a)

(b)

Figure 4.4 Experimental results. (a) An original image. (b) A tile-overlapping mosaic image. (c) Enlarged image from the red region of (b). (d) A tile-overlapping mosaic image with white holes.

(c)



(d)

Figure 4.4 Experimental results. (a) An original image. (b) A tile-overlapping mosaic image. (c) Enlarged image from the red region of (b). (d) A tile-overlapping mosaic image with white holes. (continued)

4.4 Proposed Method for Data Hiding in Tile-Overlapping Mosaic Images

4.4.1 Concept of Proposed Method

The main concept of the data hiding process in a tile-overlapping mosaic image is to utilize the overlapping degree of every pair of adjacent tile images in a tile-overlapping mosaic image.

As shown in Figure 4.5(a), first, we input a bit sequence of the secret message

Mes_i and a bit sequence of a watermark $Water_i$. By applying the data combination and disarrangement processes proposed in Section 3.3.2, we can derive a bit sequence of disordered data $DData_i$. Second, we perform the tile overlapping scheme which will be discussed in Section 4.4.2 to deal with $DData_i$. Finally, we utilize the derived overlapping degree to create a tile-overlapping mosaic image by applying the image creation process proposed in Section 4.3.2.

Referring to the concept of the data extraction process shown in Figure 4.5(b), by applying the overlapping detection process, which will be proposed in Section 4.4.3, we can extract $DData_i$ from a stego-tile-overlapping mosaic image. Finally, by applying the data recovery and separation processes proposed in Section 3.3.5, we can derive the embedded Mes_i and $Water_i$.

4.4.2 Data Hiding Process

Before performing the data hiding process in a tile-overlapping mosaic image, we process the cover image in advance. If the RGB values of a pixel in the cover image are (0, 0, 0) or (1, 1, 1), we replace them with the RGB values (0, 0, 1). The two colors (0, 0, 0) and (1, 1, 1) are reserved for special purposes as described in the following. This process of color changes is necessary for the data extraction process.

The major step of the proposed data hiding process is to take sequentially 3-bit sequences from the prefix of a randomized version of the secret message as overlapping degree values and run the proposed image creation process (Algorithm 4.3) to embed them into the cover image.

In case a hole is created using a certain overlapping degree, we have to eliminate the hole by adjusting the horizontal or vertical position of the tile with respect to its left or upper tile image, respectively, as mentioned previously. But then the overlapping degree is changed, meaning that the originally embedded 3-bit sequence is changed such that the embedding must be abandoned. This says equivalently that if we have to adjust the position of some tile image in one direction (horizontal or vertical) to avoid creating a hole, the overlapping in this direction should *not* be used to hide secret data anymore. In such a case, the overlapping on the other direction can be tried, or the next tile image should be used if the overlappings of both directions are unusable.

In addition, data extraction to be described later is conducted in a raster scan order; the tile image (denoted by *RT*) to the *right* of the currently-processed one (denoted by *CT*) will be the next to be processed for data extraction. We access the right-sided tile along a line drawn from the center of *CT* to the right. Therefore, to assure the accessibility of the *RT* in this way, we limit the center of *RT* to be located in a range *RA* (e.g., −3 pixels to +10 pixels for 32×32 tile images in this study) with respect to the center of *CT* both in the horizontal and vertical directions. Furthermore, similar to the case of hole elimination, when the position of *RT* is adjusted in either the horizontal or the vertical direction, it means that the overlapping in that direction cannot be used for data embedding.

When the position of *RT* need be adjusted due to hole elimination or/and *RT* accessibility, we say that *the position is illegal*. We move an *RT* with an illegal position horizontally or vertically for a *random* distance in the range *RA* mentioned above. The random distance is generated by a random number generator. Note that both hole elimination and *RT* accessibility must be accomplished, when necessary.

Furthermore, if secret data cannot be embedded in the horizontal (or vertical) direction, we draw *as a mark* the left and right (or upper and lower) borders with the color value of (1, 1, 1). Contrastively, for those overlappings into which secret data are embedded, the respective borders are drawn to be of the color value of (0, 0, 0). In this way, by detecting the color of a tile border, we know whether a 3-bit sequence is hidden in the tile image or not. The detail of the data hiding process is described as an algorithm as follows.

Algorithm 4.5: data hiding in a tile-overlapping mosaic image.

Input: an cover image *I*, a secret message Mes_i, a watermark $Water_i$, and a secret key K_i.

Output: a stego-tile-overlapping mosaic image *S*.

Steps:

Step 1. For each pixel, we replace the RGB values (0, 0, 0) or (1, 1, 1) with the RGB values (0, 0, 1).

Step 2. Create an empty array *A*.

Step 3. Transform the value of the message size into a bit sequence $MSize_i$ whose size is defined to nine.

Step 4. Divide $MSize_i$ into three parts with equal lengths.

Step 5. Transform each part of $MSize_i$ into a decimal integer and add it to *A*.

Step 6. Use K_i, Mes_i, and $Water_i$ to derive disordered data $DData_i$ by applying Algorithm 3.3 in Section 3.3.2.

Step 7. Divide $DData_i$ into several parts with a size of three.

Step 8. Transform each part of $DData_i$ into a decimal integer and add it to *A*.

Step 9. Take the array *A* which contains the overlapping values to run the image creation process described in Section 4.3.2.

Step 10. Draw a border of the tiles according to the result of Algorithm 4.4. If result is legal, draw the border with the RGB values (0, 0, 0); otherwise, draw that with the RGB values (1, 1, 1).

4.4.3 Data Extraction Process

The main concept of the data extraction process is to figure out the overlapping degree of every pair of adjacent tile images in a stego-tile-overlapping mosaic image. Because we replace each pixel with the RGB values (0, 0, 0) and (1, 1, 1) with that (0, 0, 1) in advance, there will be no pixel with the RGB values (0, 0, 0) or (1, 1, 1) except the borders. We utilize these borders to perform the overlapping detection process. It is another function to judge whether a bit is hidden or not by two colors of these borders. After this process, we get the disordered data $DData_i$ of the combined bit sequence of Mes_i and $Water_i$. Finally, we apply the data recovery and separation processes proposed in Section 3.3.5 to recover the embedded data (Mes_i and $Water_i$).

Algorithm 4.6: data extraction process.

Input: a stego-tile-overlapping mosaic image *S* and a secret key *Key*.

Output: a bit sequence of a secret message Mes_i and a bit sequence of a watermark $Water_i$.

Steps:

Step 1. Use Algorithm 4.7 to find the values of the three overlapping degrees on the first four tile images of the first column in *S*.

Step 2. Transform these three values into a bit sequence in order. Then transform the bit sequence into a decimal integer. Multiply the integer value by eight and take the result as the secret message size *MSize*.

Step 3. Use Algorithm 4.7 below to find other overlapping degrees from each pair of adjacent tile images in *S* in an order as shown in Figure 4.6.

Step 4. Transform the values derived from Step 3 into a bit sequence as the disordered data $DData_i$.

Step 5. Take $DData_i$, the secret key *Key*, and *MSize* to run the data recovery and separation processes proposed in Section 3.3.5 to get Mes_i and $Water_i$.

Algorithm 4.7: process for detection of overlapping degree between adjacent two tile images.

Input: a pair of adjacent tile images T_1 and T_2.

Output: the value of the overlapping degree V.

Steps:

Step 1. If T_2 overlap the bottom side of T_1, go to Step 2; if the right side, go to Step 3.

Step 2. Detect the overlapping degree of the y direction in the following way:

2.1. Scan downward pixel by pixel from the center of T_1 until meeting a pixel PY with RGB values (0, 0, 0) or (1, 1, 1).

2.2. Regard the y coordinate of T_2 as that of PY.

2.3. Calculate V by subtracting the y coordinate of T_2 from that of the bottom side of T_1.

2.4. If the RGB values of the coordinates of T_2 are (1, 1, 1), abandon this V.

Step 3. Detect the overlapping degree of the x direction in the following way:

3.1. Scan rightward pixel by pixel from the center of T_1 until meeting a pixel PX with RGB values (0, 0, 0) or (1, 1, 1).

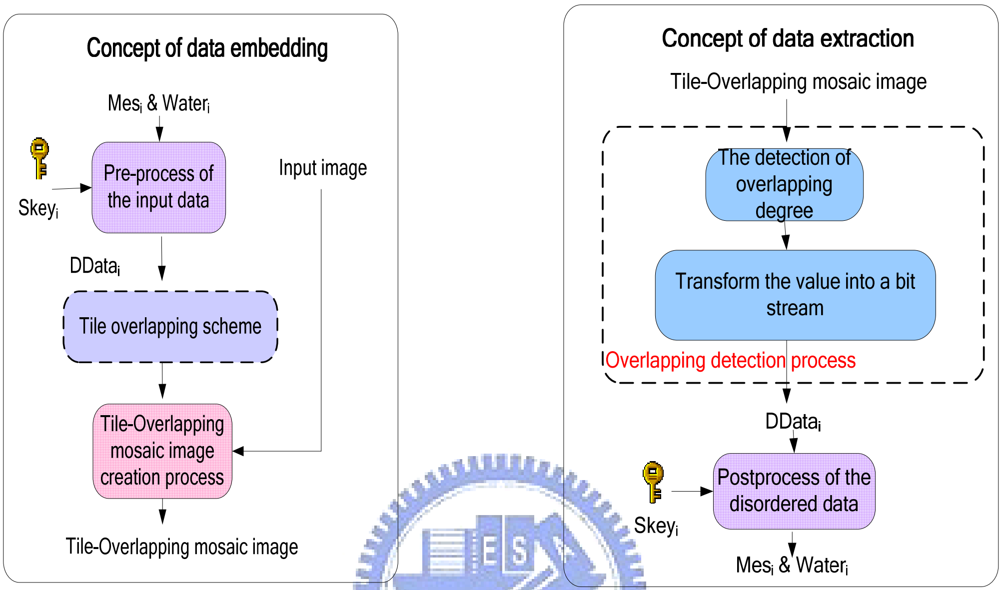
3.2. Regard the x coordinate of T_2 as that of PX.

3.3. Calculate V by subtracting the x coordinate of T_2 from that of the rightmost of T_1.

3.4. If the RGB values of the coordinates of T_2 are (1, 1, 1), abandon this V.

4.4.4 Experimental Results and Discussions

Figure 4.7 shows some experimental results of proposed data hiding in a tile-overlapping mosaic image. Figure 4.7 (a) is a tile-overlapping mosaic image with the secret message, “這是一架戰鬥機的圖片,” and the watermark, Figure 4.7(c), embedded. Figure 4.7(b) is the secret message extracted from Figure 4.7(a) with a correct key. Figure 4.7(d) is the watermark extracted from Figure 4.7(a) with a correct key. Figure 4.7(e) shows the extraction results from Figure 4.7(a) with a wrong key.



(a) (b)

Figure 4.5 Core concepts of data embedding and extraction of a tile-overlapping mosaic image.

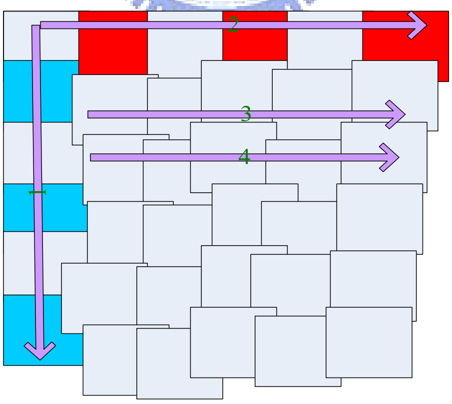
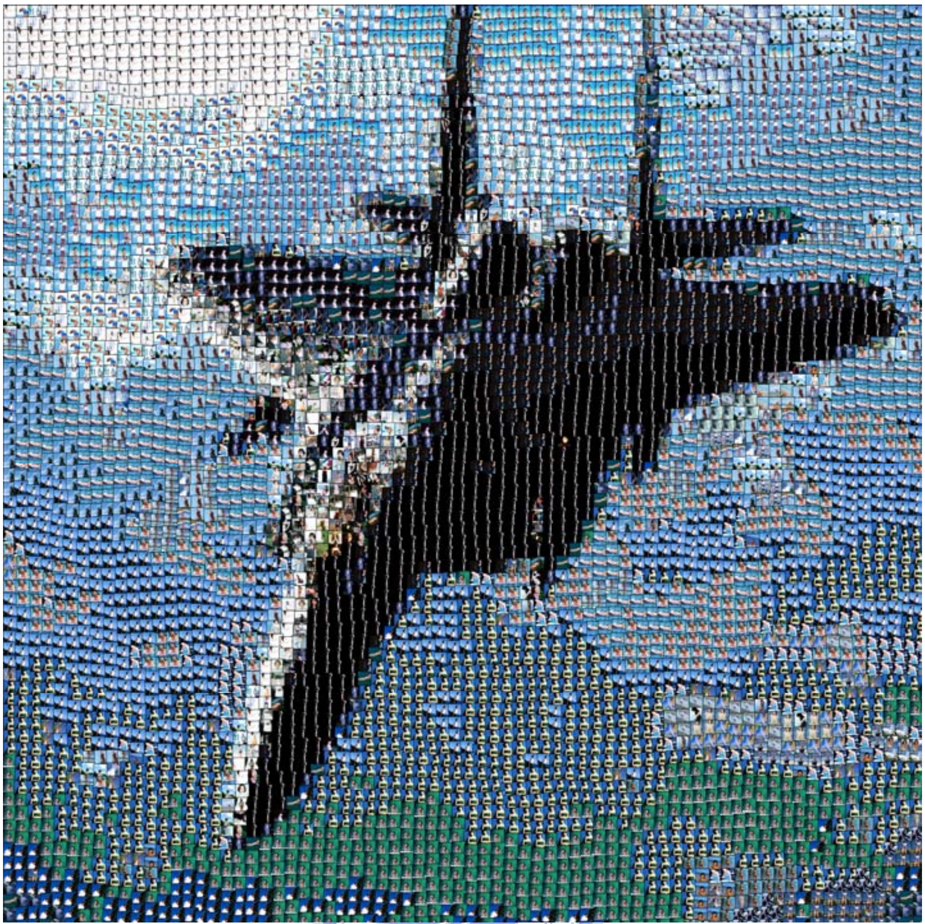
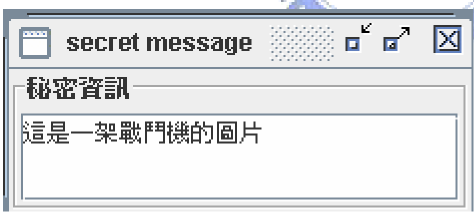


Figure 4.6 The order of the image creation, data hiding and extraction processes.

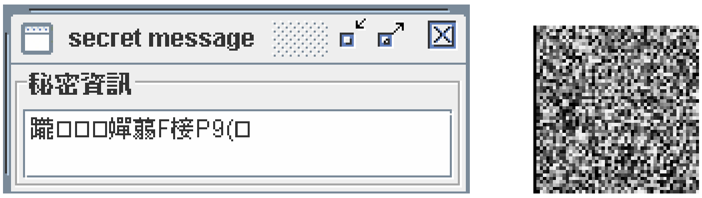


(a)



(c) (d)

(b)



(e)

Figure 4.7 Experimental results of data hiding in a tile-overlapping mosaic image. (a) A tile-overlapping mosaic image with the secret message and watermark (c) embedded. (b) The secret message extracted from (a) with a correct key. (d) A watermark extracted from (a) with a correct key. (e) The extraction results from (a) with a wrong key.

Chapter 5
Creation of Variable-Sized Mosaic Images for Information Hiding

5.1 Overview of Proposed Method

In this chapter, we propose another new-styled mosaic images which differ from the traditional ones. Because the sizes of the tile images in the proposed mosaic image are not uniform, we name the resulting art image a *variable-sized mosaic image*. We use tile images of two sizes, 16×16 and 32×32 pixels, to construct the mosaic image. We change the sizes of tile images dynamically during the image creation, so we face some problems, such as holes or overlapping areas. Fortunately, we found a check mechanism to solve these problems. We also utilize the characteristics of the tile sizes to achieve the purpose of data hiding. For example, we use small blocks with the size of 16×16 to represent bit 0 and large blocks with the size of 32×32 to represent bit 1. In this way we can hide data into the proposed new-styled mosaic image. The data extraction process is just the inverse version of the data hiding one. The details of these techniques will be described in the following sections.

5.2 Proposed Variable-Sized Mosaic Image Creation Method

5.2.1 Idea of Image Creation Process

Lin [17] proposed methods for forming tiles with dot and hexagon shapes. Some experimental results of their study are shown in Figure 5.1 and Figure 5.2. The idea of the proposed method to be described subsequently comes from this study. He changed the shape of the tile image. However, we change the size of the tile image to form the proposed mosaic image. The two sizes of the tile image in the created image are 16×16 and 32×32. We compose all of the tile images with these two sizes to produce a variable-sized mosaic image. It is important to avoid causing overlapping areas during the image creation process. So, we must examine the appropriateness of the size of a tile image by the checking process described later before it can be drawn. The detail of the image creation process is described in the next section.

Table 5.1 A matching table for the size of the tile image.

A given bit	representation
0	Big tile size with 32×32 pixels
1	Small tile size with 16×16 pixels

5.2.2 Detail of Image Creation Process

In this section we show how to create a variable-sized mosaic image. The major steps are as follows.

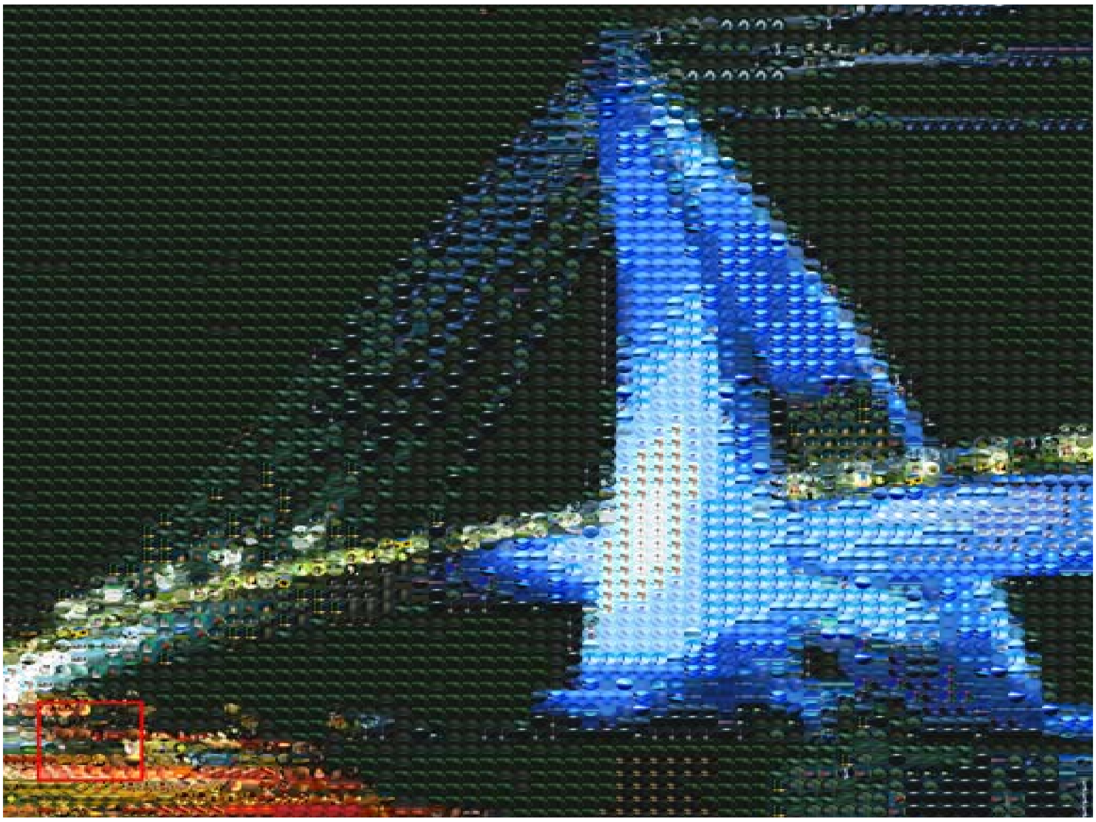
(1) Construct two tile image databases by Algorithm 4.2 proposed in Section 4.1.2. One is for the tile with size 32×32 pixels and the other is for that with size 16×16 pixels.

(2) Resize the original image to the scale of 2048×2048 pixels.

(3) Draw a tile in the raster scanning order. The size of the tile is randomly selected from the above two sizes and is checked to see whether there is enough space to insert a tile before the tile is drawn.

(4) Repeat the above step until all tiles are processed.

The detail of the image creation process is described as an algorithm as follows.



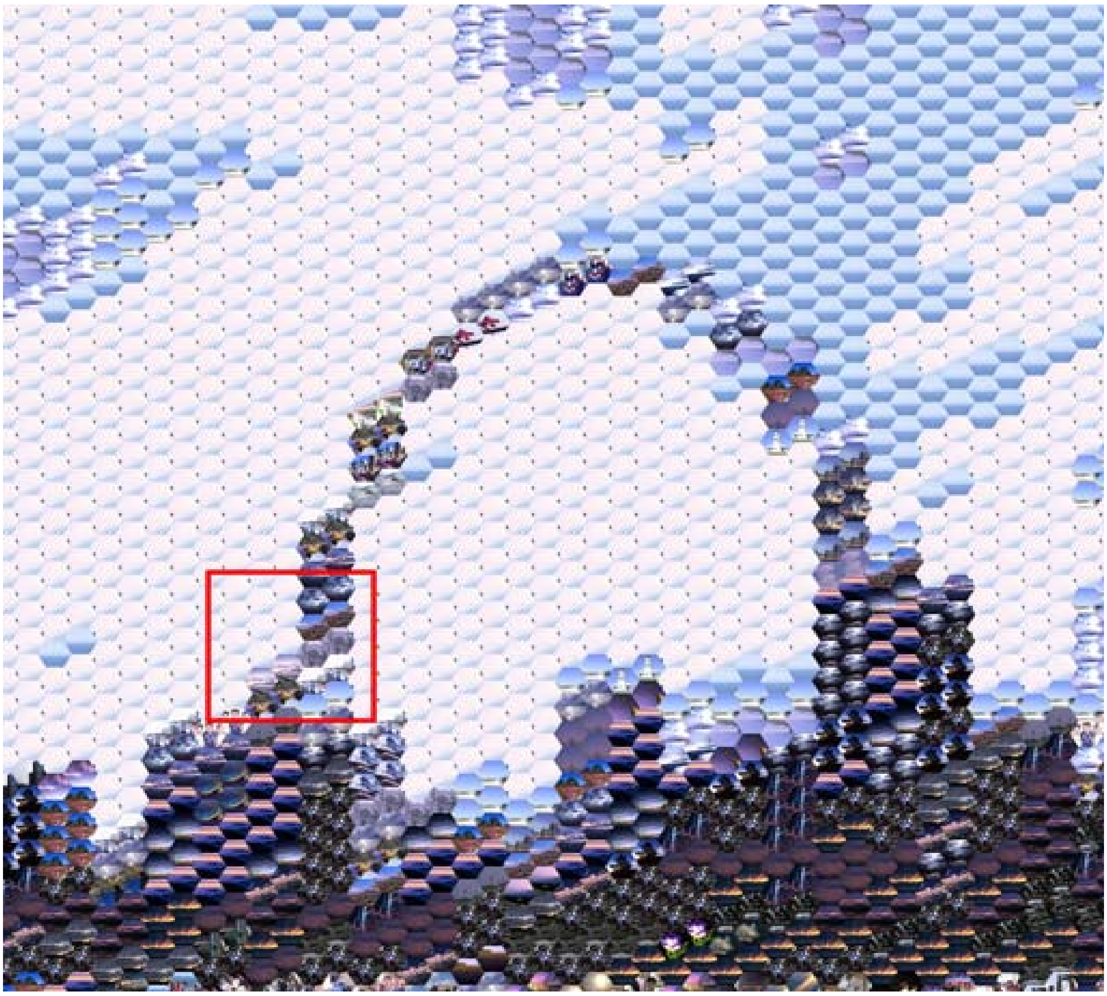
(a)

Figure 5.1 Some experimental results of Lin [17]. (a) The mosaic image of using dotted tile shapes. (b) The tile images of the red region of (a). (c) The original image.

(b)

(c)

Figure 5.1 Some experimental results of Lin [17]. (a) The mosaic image of using dotted tile shapes. (b) The tile images of the red region of (a). (c) The original image. (continued)



(a)

Figure 5.2 Some experimental results of Lin [17]. (a) The mosaic image of using hexagonal tile shapes. (b) The tile images of the red region of (a). (c) The original image.

(b)

(c)

Figure 5.2 Some experimental results of Lin [17]. (a) The mosaic image of using hexagonal tile shapes. (b) The tile images of the red region of (a). (c) The original image. (continued)

Algorithm 5.1: variable-sized mosaic image creation process.

Input: an input image *I*.

Output: a variable-sized mosaic image for I'.

Steps:

Step 1. Use Algorithm 4.2 proposed in Section 4.1.2 to construct two tile image databases DB_1 and DB_2 for the two sizes 16×16 and 32×32, respectively.

Step 2. Resize *I* to the scale of 2048×2048, resulting in a new image I'.

Step 3. Create an array $A = \{A_1, A_2, \ldots, A_n\}$ and randomly set each element to be 0 or 1.

Step 4. Denote the size of a tile $T_{i,j}$ as $Size_{i,j}$ and *F* as the best matching tile image from DB_1 or DB_2 with a target image of I'.

Step 5. Process the tiles in a raster scan order in the following way.

5.1. Get the tile size by taking an element A_i from *A* and check the matching table shown in Table 5.1.

5.2. Checking whether there is enough space to insert this tile. If the result is not, we replace the tile, if large, with a small one, i.e., 16×16.

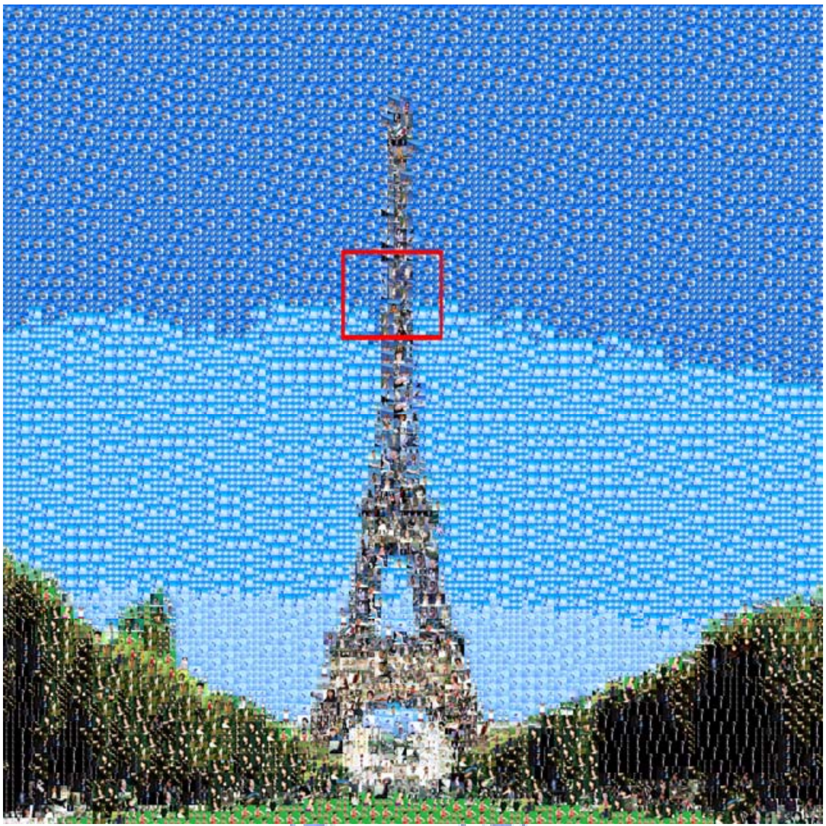
5.3. Draw *F* according to the tile size row by row until the entire tiles are processed.

5.2.3 Experimental Results and Discussions

Figure 5.3(a) is an original image. Figure 5.3 (b) is the corresponding variable-sized mosaic image created by applying the above process. Figure 5.3 (c) is the tile images of the red region in Figure 5.3 (b). We can observe from Figure 5.3 (c) that there is no overlapping area. Figure 5.4 and Figure 5.5 show some other experimental results.

(a)

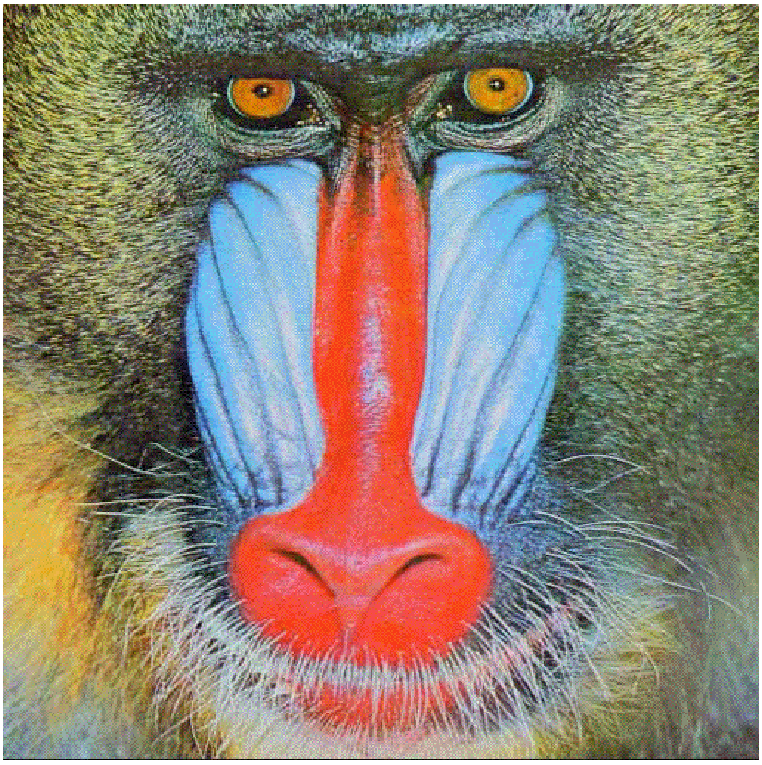
Figure 5.3 Some experimental results of the proposed image creation process. (a) An original image. (b) A variable-sized mosaic image created from (a). (c) An image composed of several tile images of the red region in (b).



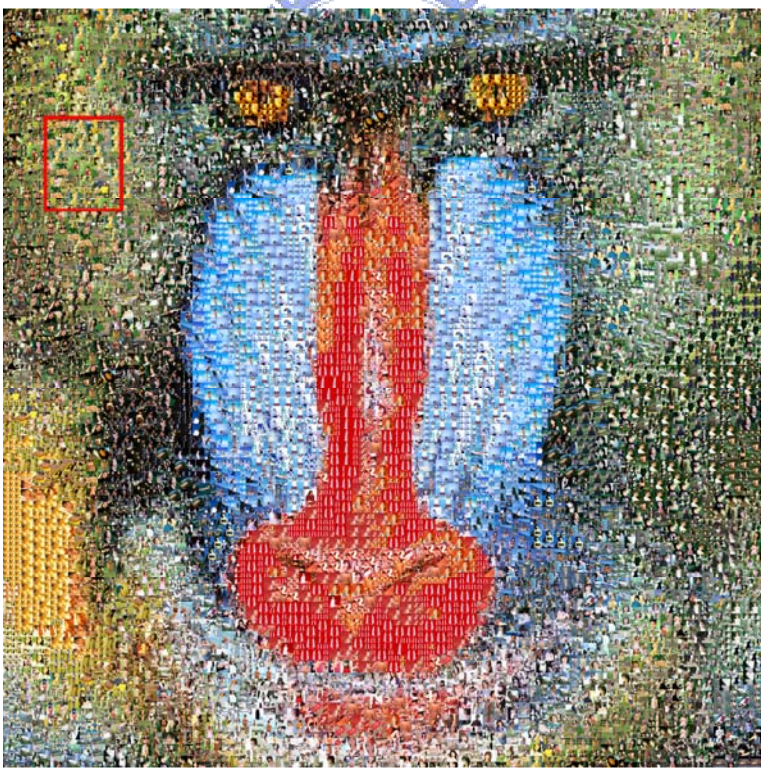
(b)

(c)

Figure 5.3 Some experimental results of the proposed image creation process. (a) An original image. (b) A variable-sized mosaic image created from (a). (c) An image composed of several tile images of the red region in (b). (continued)



(a)

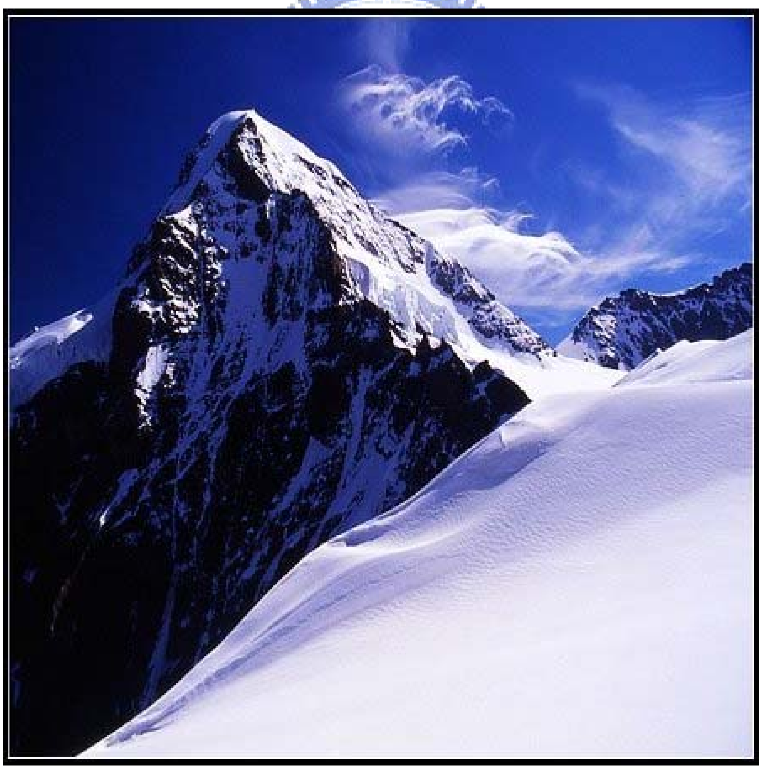


(b)

Figure 5.4 Some experimental results of proposed image creation. (a) An original image. (b) A variable-sized mosaic image created from (a). (c) An image composed of several tile images of the red region in (b).

(c)

Figure 5.4 Some experimental results of proposed image creation. (a) An original image. (b) A variable-sized mosaic image created from (a). (c) An image composed of several tile images of the red region in (b). (continued)



(a)

Figure 5.5 Some experimental results of proposed image creation. (a) An original image. (b) A variable-sized mosaic image created from (a). (c) An image composed of several tile images of the red region in (b).

(b)

(c)

Figure 5.5 Some experimental results of proposed image creation. (a) An original image. (b) A variable-sized mosaic image created from (a). (c) An image composed of several tile images of the red region in (b). (continued)

5.3 Proposed Method for Data Hiding in Variable-Sized Mosaic Images

5.3.1 Concept of Proposed Method

The main concept of the proposed method for data hiding in a variable-sized mosaic image is to utilize the variability of the size of the tile image. We can hide data bits into the tile images by taking a bit sequence of a given secret message as an input array A to produce an image by applying the proposed image creation process described previously. In the data extraction part, detecting the tile size with no borders from the resulting image is too hard, so we proposed a method to solve this problem. We must modify slightly the specific pixel of each tile image. If the tile size is large, we set the RGB values of the specific pixel to the even values nearest to the original ones, respectively; and if the tile size is small, we set them to the odd values nearest to the original ones, respectively. The details will be stated clearly in Sections 5.3.2 and 5.3.3.

5.3.2 Data Hiding Process

As mentioned previously, the main idea behind the proposed data hiding process is to utilize the tile size according to an array with hidden bits. Simply speaking, we get the appropriate size for the tile image to be drawn according to a hidden bit by checking the matching table shown in Table 5.1. In order to avoid producing overlapping areas, we enforce the tile size to be adjusted in above-mentioned manner. Then, we modify slightly a specific pixel in the tile image to mark the tile size by Algorithm 5.3. Finally, we compose all the tile images together to produce a stego-variable-sized mosaic image. The detail of the data hiding process is described as an algorithm as follows.

Algorithm 5.2: data hiding in a variable-sized mosaic image.

Input: an image *I*, a secret message Mes_i, and a secret key *K*.

Output: a stego-variable-sized mosaic image for I'.

Steps:

Step 1. Create an empty array *A*.

Step 2. Convert the secret message size into a bit sequence with a size of 10 and add it to *A* in order.

Step 3. Take Mes_i and a secret key *K* to derive a disordered data $DData_i$ by Algorithm 3.3 in Section 3.3.2.

Step 4. Add $DData_i$ to *A* in order.

Step 5. Take *A* as an input array to run the image creation process proposed in Section 5.2.2.

Step 6. Modify slightly a specific pixel of each tile image by Algorithm 5.3.

Algorithm 5.3: modify the RGB values of a specific pixel.

Input: a tile image *T* and a secret key *K*.

Output: a modified tile image T'.

Steps:

Step 1. Use *K* as an input to run a random number generator and get a random integer *RI* ranging from 0 to 255.

Step 2. Get the coordinates of a specific pixel *P* in the following way:

2.1. Take the *x* coordinate of *P* to be the value of *RI* divided by 16.

2.2. Take the *y* coordinate of *P* to be the remainder of *RI* divided by 16.

Step 3. Modify the RGB values of *P* in the following way:

3.1. if the tile size is large, set the RGB values of P to the even values nearest to the original ones, respectively;

3.2. otherwise, set the RGB values of P to the odd values nearest to the original ones, respectively.

5.3.3 Data Extraction Process

The main concept of the data extraction process is to figure out the size of each tile. It is the most important issue that not every tile hides a bit. Therefore, we must judge whether a bit is hidden or not into a tile. If we met a space which cannot fit a large tile, then this tile contain no hidden bit. The data extraction process is described as an algorithm as follows.

Algorithm 5.4: data extraction process.

Input: a stego-variable-sized mosaic image S and a secret key K.

Output: a bit sequence of a secret message Mes_i.

Steps:

Step 1. Get the secret message size from the first ten tile images.

1.1. Use Algorithm 5.5 to process the first ten tile images and store the extracted bits to an array A_1 in order.

1.2. Convert the array A_1 into a decimal value which is just the secret message size *MSize*.

Step 2. Use Algorithm 5.5 to process other tile images and add the extracted bits to an array A_2 in order.

Step 3. Take A_2 and the secret key K to derive Mes_i by Algorithm 3.8 in Section 3.3.5.

Algorithm 5.5 extracting a hidden bit from a tile image.

Input: a tile image *T* and a secret key *K*.

Output: a hidden bit *B*.

Steps:

Step 1. If there is not enough space to insert a large tile, go to Step 2, otherwise go to Steps 3.through 6.

Step 2. There is no hidden bit can be extracted from this tile image.

Step 3. Use *K* as an input to run a random number generator and get a random integer *RI* ranging from 0 to 255.

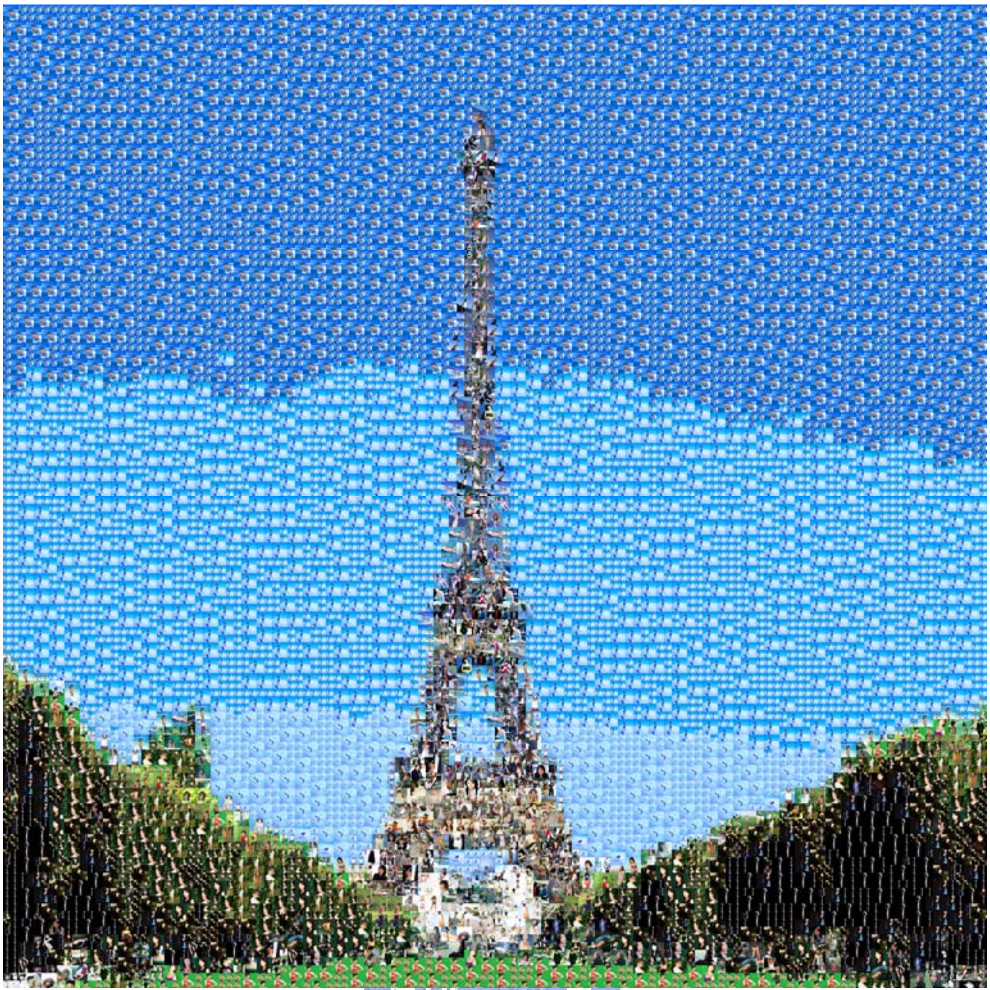
Step 4. Use Step 2 of Algorithm 5.3 to get the coordinates of the specific pixel *P* of *T*.

Step 5. Judge the RGB values of *P* are even or odd. If the values are even, the tile size is large; otherwise, the tile size is small.

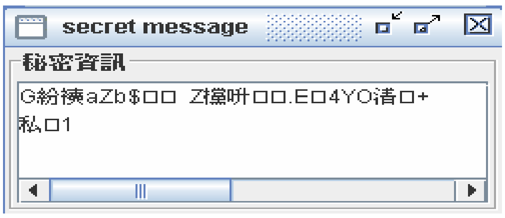
Step 6. Take the tile size to check the matching table shown in Table 5.1 to get a hidden bit *B*.

5.3.4 Experimental Results and Discussions

Figure 5.6, Figure 5.7, and Figure 5.8 show some experimental results of data hiding in variable-sized mosaic images. Figure 5.6(a) is a stego-variable-sized mosaic image with the secret message, "巴黎鐵塔." Figure 5.6(b) is the secret message extracted from Figure 5.6 (a) with a correct key. Figure 5.6(c) is the secret message extracted from Figure 5.6 (a) with a wrong key. Figure 5.7(a) is a stego-variable-sized mosaic image with the secret message, "狒狒 baboon." Figure 5.7(b) is the secret message extracted from Figure 5.7(a) with a correct key. Figure 5.7(c) is the secret message extracted from Figure 5.7(a) with a wrong key. Figure 5.8(a) is a stego-variable-sized mosaic image with the secret message, "白雪皚皚." Figure 5.8(b) is the secret message extracted from Figure 5.8(a) with a correct key. Figure 5.8(c) is the secret message extracted from Figure 5.8(a) with a wrong key.

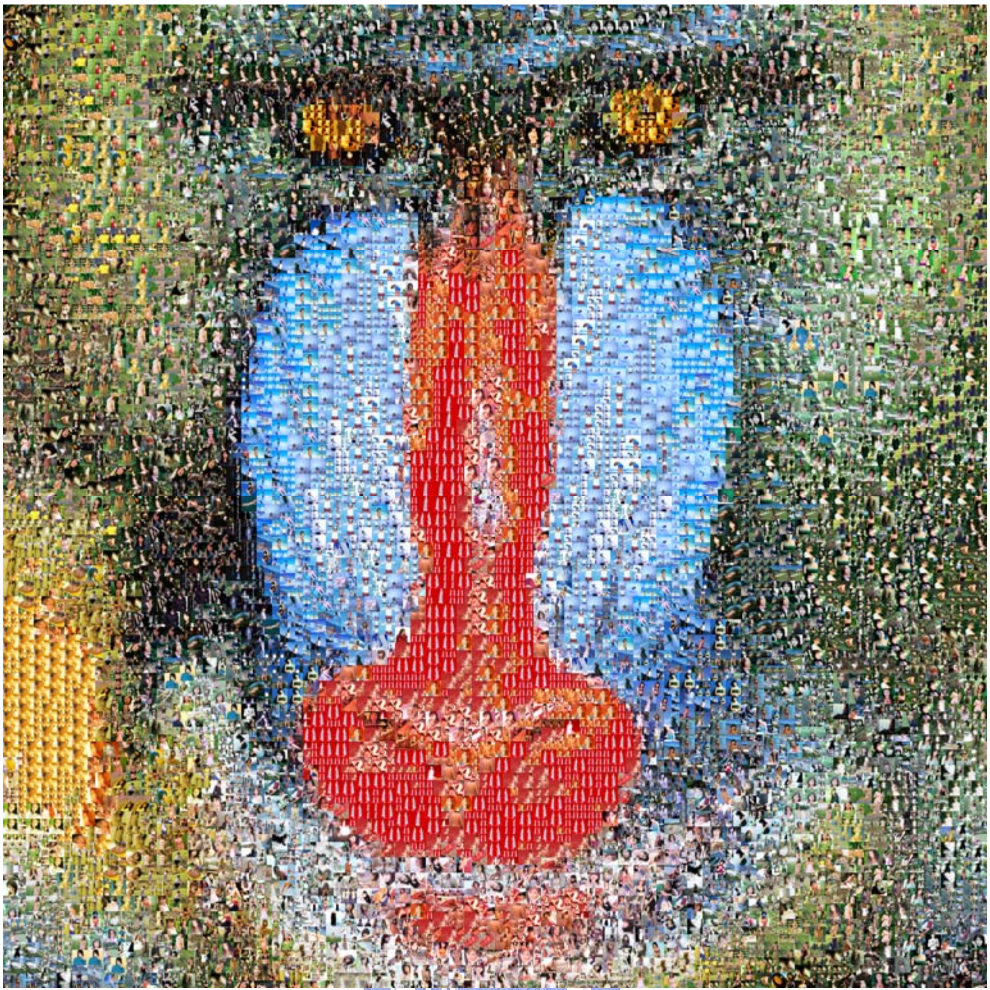


(a)

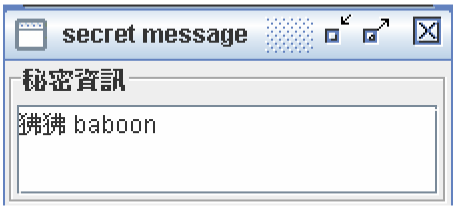


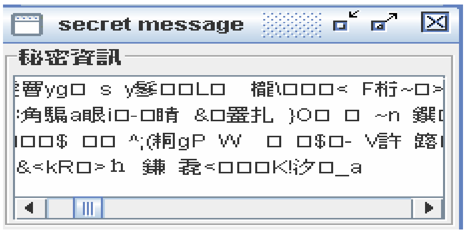
(b) (c)

Figure 5.6 Experimental results of data hiding in variable-sized mosaic image. (a) A stego-variable-sized mosaic image. (b) The secret message extracted from (a) with a correct key. (c) The secret message extracted from (a) with a wrong key.



(a)

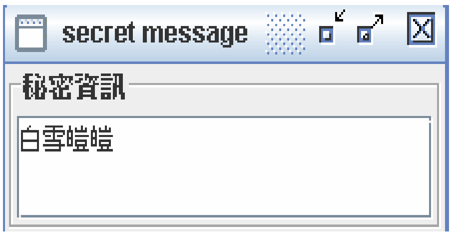




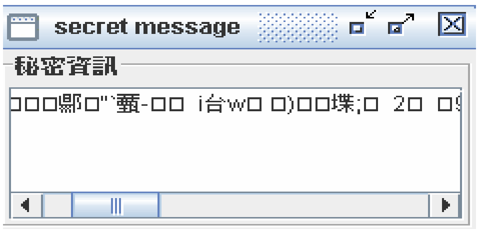
(b) (c)

Figure 5.7 Experimental results of data hiding in variable-sized mosaic image (a) A stego-variable-sized mosaic image. (b) The secret message extracted from (a) with a correct key. (c) The secret message extracted from (a) with a wrong key.

(a)



(b)



(c)

Figure 5.8 Experimental results of data hiding in variable-sized mosaic image. (a) A stego-variable-sized mosaic image. (b) The secret message extracted from (a) with a correct key. (c) The secret message extracted from (a) with a wrong key.

Chapter 6
Conclusions and Suggestions for Future Works

6.1 Conclusions

In this study, we have proposed three methods for creation of art images of new types and data hiding in them. We can apply these methods for various information hiding applications, such as covert communication, copyright protection, etc. Different from traditional data hiding techniques, we hide data in the individual features of the created art images.

The three different types of art images created in this study are irregular-hexagonal-tiled image, tile-overlapping mosaic image, and variable-sized mosaic image.

For irregular-hexagonal-tiled images, we use two features for image creation and data hiding. One is the variation of two specific vertices of a hexagonal tile, and the other is the RGB values of the center of a tile. We combine a secret message and a watermark to form a bit sequence before performing the data hiding process. By modifying the locations of the two specific vertices and the RGB values of the center of every hexagonal tile, we can achieve the data hiding work.

In tile-overlapping mosaic images, we use one feature for image creation and data hiding, that is, the overlapping degree of every pair of adjacent tile images. Due to some special cases of tile arrangements, holes might be created during the image creation process. We solve this problem by restricting the tile location in a specific range between the current tile and the preceding one of the left and upper side. We can achieve the data hiding work by an overlapping scheme which utilizes the overlapping degrees of adjacent tiles.

For variable-sized mosaic images, we use only one feature for image creation and data hiding, that is, the size of the tile image. We also proposed a solution to avoid causing overlapping areas during the image creation process. The solution is based on checking the sizes of three neighboring tiles to see whether there is enough space to insert the large tile. By adjusting the tile size according to a bit sequence of given message data, we can achieve the purpose of data hiding.

6.2 Suggestions for Future Works

In this study, we have proposed some methods for creation of irregular-hexagonal-tiled images, tile-overlapping mosaic images, and variable-sized mosaic images, as well as data hiding techniques for these three types of art images. The two applications, secret communication and copyright protection, may be carried out by utilizing the proposed data hiding techniques. However, there are still some interesting topics which are worth for further study. They are listed as follows.

1. Producing mosaic images with other shapes based on computer graphics.
2. Combining two proposed data hiding methods and applying them to a mosaic image for a larger bit hiding capacity.
3. Using more tile features for embedding more data into mosaic images.
4. Detecting the tile borders to speed up data extraction by applying a more complicated image analysis process for a mosaic image composed of many tile images.

5. Creating other types of art images and selecting appropriate image features to achieve corresponding data hiding works.
6. Keeping the image quality good after embedding data in it.

References

[1] Y. W. Guo, J. H. Yu, X. D. Xu, and Q. S. Peng, "Example based painting generation," *Journal of Zhejiang University: Science*, Vol 7, No 7, pp. 1152-1159, July 2006.

[2] G. C. Chen, "Automatic Generation of Pencil Sketching with the Effects of Paper Texture," *M. S. Thesis*, Department of Computer and Information Science, National Chiao Tung University, Hsinchu, Taiwan, Republic of China, June 2006.

[3] B. Baxter, V. Scheib, M. C. Lin, and D. Manocha, "DAB: Interactive haptic painting with 3D virtual brushes," *Proceedings of SIGGRAPH 01*, pp. 461-468, Auguest 2001.

[4] Von Laerhoven, Tom and Van Reeth, Frank, "Real-time simulation of watery paint," *Computer Animation and Virtual Worlds*, Vol 16, No 3-4, pp. 429-439, July 2005.

[5] A. Hertzmann, "Painterly Rendering with Curved Brush Strokes of Multiple Sizes," *Proceedings of SIGGRAPH 98*, pp. 453-460, Orlando, Florida, July 1998.

[6] C. J. Curtis, S. E. Anderson, J. E. Seims, K. W. Fleischer, and D. H. Salesin, "Computer-generated watercolor," *Proceedings of SIGGRAPH 97*, pp. 421-430, August 1997.

[7] U. N. Chen, "Non-Photorealistic 3D Rendering in Chinese Painting Style," *M. S. Thesis*, Department of Computer Science and Information Engineering, National Cheng Kung University, Tainan, Taiwan, Republic of China, July 2003.

[8] K Kojima, S Takahashi, T Nishita, "Creating Quadrilateral Mosaics from Image

Topographic Features," *Proceedings of the 3rd symposium on Applied perception in graphics and visualization*, 2006.

[9] Paul E. Haeberli, "Paint by Numbers: Abstract Image Representations," *Proceedings of SIGGRAPH 90*, pp. 207-214, August 1990.

[10] Alejo Hausner, "Simulating Decorative Mosaics," *Proceedings of SIGGRAPH 01*, pp. 573-580, New York, USA, 2001.

[11] Hoff, K., Keyser, J., Lin, M., Manocha, D. and Culver, T. "Fast Computation of Generalized Voronoi Diagrams Using Graphics Hardware," *Proceedings of SIGGRAPH 99*, pp. 277-286, August 1999.

[12] S. P. Lloyd, "Least Square Quantization in PCM," *IEEE Transactions on Information Theory*, Vol. IT-28, No. 2, pp. 129-137, March 1982.

[13] D. C. Wu and W. H. Tsai, "A Steganographic Method for Images by Pixel-Value Differencing," *Pattern Recognition Letters*, Vol. 24, No. 9-10, pp. 1623-1636, 2003.

[14] Y. C. Chiu and W. H. Tsai, "Copyright protection by watermarking for Color Images against Rotation and Scaling Attacks Using Peak Detection and Synchronization in Discrete Fourier Transform Domain," *Proceedings of Third Workshop on Digital Archives Technologies*, pp. 207-213, Taipei, Taiwan, August 5-6, 2004.

[15] Z. Ni, Y. Q. Shi, N. Ansari, and W. Su, "Reversible data hiding," *Proceedings. IEEE Int. On Cirsuits and Systems*, Vol. 2, pp. 912-915, Bangkok, Thailand, May 25-28, 2003.

[16] Y. J. Cheng, C. Y. Yin, D. C. Wu, and W. H. Tsai, "Copyright protection and authentication of image information in digital libraries," *Proceedings of 2001 Conference on Trends and Perspectives in Digital libraries and Digital Museums*, Vol 3, pp. 1-11, Hsinchu, Taiwan, Republic of China.

[17] W. L. Lin, “Data hiding in image mosaics,” *M. S. Thesis*, Department of Computer and Information Science, National Chiao Tung University, Hsinchu, Taiwan, Republic of China, June 2004.

[18] S. C. Hung, “Data hiding in art images,” *M. S. Thesis*, Department of Computer and Information Science, National Chiao Tung University, Hsinchu, Taiwan, Republic of China, June 2005.

[19] C. Y. Hsu and W. H. Tsai, “Creation of a new type of image - circular dotted image - for data hiding by a dot overlapping scheme,” *Proceedings of Conference on Computer Vision, Graphics and Image Processing*, Taoyuan, Taiwan, Republic of China, 2006.

[20] C. Y. Hsu, “A study on art image generation and information hiding,” *M. S. Thesis*, Department of Computer Science and Engineering, National Chiao Tung University, Hsinchu, Taiwan, Republic of China, June 2006.