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影像馬賽克上的資訊隱藏

Data Hiding in Image Mosaics

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中 華 民 國 九 十 三 年 六 月

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摘要

影像馬賽克(Image Mosaics)是由許多小圖所組合而成的一種影像，其中每一小圖都被安排貼至一與原始影像極為相似的區塊，因此當在遠處觀看時，影像馬賽克會呈現成一幅與原始影像相似的影像。在本論文中，我們除了建立一套創造影像馬賽克的系統外，並提出三種方法來製造不同效果的影像馬賽克，包括產生不同形狀的小圖、控制小圖出現的次數，與修改其顏色等。另外，針對此類型影像大多應用至海報、廣告看板等目的，我們提出一種可植入半可視浮水印(semi-visible watermark)於小圖邊界來保護影像馬賽克版權的方法。被保護的影像馬賽克即使經過「列印後再掃描」的破壞，我們所提方法依舊能抽出所植入的浮水印。另一方面，針對 BMP 格式的影像馬賽克，我們結合了「修改色調」與「隱藏資訊」兩個目的，提出一種新的資訊隱藏方法，能在修改每一小圖色彩的同時，將驗證訊號藏入 HSI 色彩模式中的色調(Hue)元素中，並能抽取出所藏入的訊號來驗證馬賽克影像的完整性。最後我們將拼圖遊戲的概念應用至影像馬賽克上，以重組影像馬賽克中多張小圖的方式，來傳送高解析度的秘密影像。另外，為了保證秘密傳輸的正確性，我們提出了一針對秘密影像與遮蔽影像(cover image)做雙重驗證的概念及一相對驗證方法。實驗結果顯示我們提出的方法都可以解決所面對的問題。

Data Hiding in Image Mosaics

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ABSTRACT

An image mosaic is obtained by arranging a large number of small tile images in such a way that each small image resembles a small target block of a given image, and suggests a larger image when seen from a distance. Methods for generating different shapes, enforcing the appearances, and modifying the colors of the small images are proposed for generating different image mosaics. Image mosaics may exist in digital forms or in real copies. For the purpose of copyright protection of them, a semi-visible watermark coded by the use of the boundary regions of tile images is proposed. The watermark can be embedded in an image mosaic and detected even after the image mosaic goes through a print-and-scan process. Also, utilizing the color relations between the tile images and the target blocks of the input image, a novel method for hiding data by altering the pixel values of the hue component in the HSI color model is proposed. Authentication signals can be embedded accordingly in the image mosaic with the BMP format, which can be extracted to verify the fidelity and integrity of the image mosaic. Finally, a method using the tile images of a secret image to compose an image mosaic to achieve a novel covert communication application is proposed. The method can be used to transfer high-resolution secret images behind a cover image. Image authentication may be applied to the cover image mosaic as well as the secret image simultaneously for the purpose of double authentication. Experimental results show the feasibility of the proposed methods.

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Finally, the author also extends his profound thanks to his family for their lasting love, care, and encouragement. He dedicates this dissertation to his parents.

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Introduction

1.1 Motivation

1.1.1 Introduction to Image Mosaics

An *image mosaic* is an image obtained by arranging a large number of small images, called *tile images*, in a certain way so that each tile image resembles a small block of the *original image*, called *target image*, and that all the tile images together suggest a larger image when seen from a distance. It takes advantage of a property of the human visual system that an observer will only see an average color in a region at a distance when that region is actually full of different colors. So far as an image mosaic is concerned, each tile image is an element, which represents the average color of the region and has its meaning specifically. The idea of building image mosaics automatically by computer technology comes from Silvers [1] who was a former M .I. T. Media Lab graduate student in 1996.

However, the concept of creating an image to contain many small elements comes from paintings originally, even before digital computers came into being. Impressionist painters, like Monet, Seurat, and Matisse, drew outstanding paintings with many different strokes. When people view the painting at a small distance, it appears to be a collection of small brush strokes of various colors. When observed at a larger distance, these brush strokes combine to yield an integrated impressive painting. In the 1970's, American artist Close [2] began producing grided paintings that has little aspect of visual perception. In 1976, Dali [3] has imitated a picture, presented by an article "The Recognition of Faces" in Scientific American in November 1973 written by Harmon [4] of Bell Labs. shown in Figure 1.1, to paint a famous portrait of Abraham Lincoln. He painted the masterpiece by putting many tiled images as small elements together, including one picture of his wife, as shown in Figure 1.2. In modern time, as we mentioned before, Robert Silvers used his ideas to developed a software and set up a company, which hold a trademark and methods of image mosaics creation called Photomosaic^{TM} [5] [6] in 1996.

Recently, image mosaics are still amazing with their varieties of image contents, which can say much more than only one picture and make people think. Besides obvious applications in art and entertainment, it has become a new medium for advertisement. In this study, we were not only inspired by Dali's painting *"Lincoln in Dalivision"* at the beginning to raise the wish of designing a whole framework for image mosaics creation, but also paid attention to the study of copyright protection of image mosaics. Figure 1.3 shows an image mosaic created by our method.

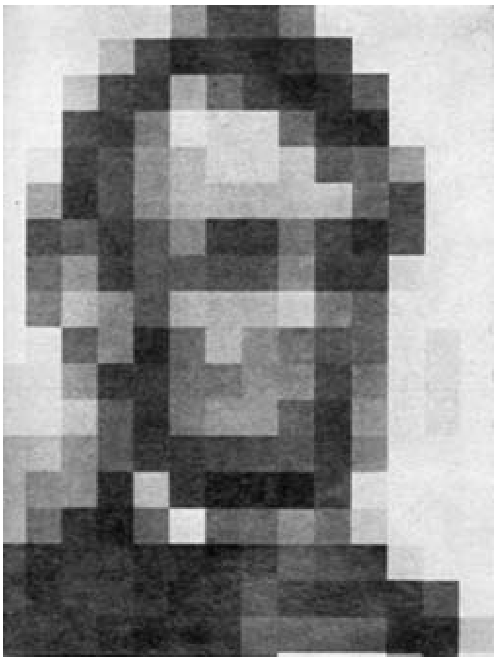


Figure 1.1 Lincoln Portrait. [by Leon Harmon].

Figure 1.2 Lincoln in Dalivision. [by Salvador Dali].

Figure 1.3 An image mosaic of Lena with 1024 small tile images.

1.1.2 Motivation of Study

With the growth of communication networks, exchanges of digital documents have become more and more convenient and fast via the Internet. However, the convenient exchanges also bring many drawbacks in copyright protection of digital documents. People can easily duplicate, modify, or tamper document contents, resulting in unreliability of digital documents. Recently, information hiding techniques has become one chief approach to achieving the goal of copyright protection and image authentication. Digital watermarking, one of information hiding techniques, is often applied to protect the copyright of digital images by detecting embedded invisible or visible watermarks in images. For the image authentication purpose, digital images can be verified by checking embedded authentication signals to see whether they are destroyed or not. In this study, we will focus on dealing with "image mosaics." An image mosaic is a special kind of digital images as discussed in the previous section. The first motivation of this work is an integration of fine art and computer technology. The automatic ability of combining groups of images to be a larger one by computers may give another solution for artists in painting. Secondly, the image mosaic will be a good media for carrying out covert communication once it becomes popular, and will face also the problems of copyright protection and authentication, just like digital images. Therefore, we go along in this study to figure out new data hiding techniques and apply them to the image mosaic by taking advantage of its characteristics for the copyright protection, image authentication and covert communication purposes. The objectives of the new data hiding techniques that we are concerned are not only how to increase the data hiding capacity but also how to improve the impression quality on the image mosaic after hiding data. In addition, the hiding scheme should be robust enough against the print-and-scan attack because the image mosaic might be printed and scanned. We also attempt to utilize the tile images of an image mosaic to achieve a new covert communication application.

1.2 Review of Related Works

1.2.1 Review of Previous Studies on Image Mosaics

Several researches investigated the problem of how to create image mosaics automatically by computers. Silvers [6] proposed firstly a proprietary method to build image mosaics using computer technology in 1996 and claimed to have a software patent on "digital composition of a mosaic image" in United States. Finkelstein and Range [7] described many methods for arranging a set of small images and adjusting their colors to create image mosaics. They solved the problem in four important steps and preformed them automatically or semi-automatically by computers. Tran [8] proposed a quantitative method for studying algorithms for generating image mosaics in accordance with the similarity between an image mosaic and the original image, the granularity of details in each individual tile, the variety of the selected tiles, the running time of the generation, and the number of tiles available for selection. Zhang, Nascimento and Zaiane [9] used content-based image retrieval techniques to describe and evaluate a few parameters that control the quality of image mosaics and then proposed an automatic measure to assess the quality of the resulting images.

1.2.2 Review of Previous Studies on Data Hiding Techniques

Many data hiding techniques have been described to hide data in digital images of different formats for various purposes. But there are fewer researches that can be applied to deal with digital image mosaics. Blundo and Galdi [10] presented a novel approach to hiding information in the tile images of an image mosaic by a cryptography scheme. They classified images in a tile image database into two categories, one standing for bit “0” and the other for bit “1”, which can encrypt an image mosaic. Ni, et al. [11] 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 [12] proposed a DCT-based method for embedding an invisible watermark by adjusting the magnitude relation of certain DCT coefficient pairs in the frequency domain. Yin and Tsai [13] proposed a method to embed an invisible watermark in JPEG images. Generally speaking, data hiding in the frequency domain is more robust than that in the spatial domain.

1.2.3 Review of Previous Studies on Image Authentication

Yin and Tsai [13] also proposed a method to embed an authentication signal in JPEG images. The image can be verified by checking the embedded authentication signals to see whether they are destroyed or not. Tzeng and Tsai [14] embedded special codes into the blocks of given images and verify them to accomplish the authentication purpose. Fridrich [15] divided an image into several large blocks and proposed the use of a spread spectrum signal as an authentication signal. The signal is integrated with a secret key, the location of a block and the content of the block and is embedded into the middle third part of the DCT coefficients. The image can be verified by comparing the correlation of the embedded spread spectrum and the extracted spectrum over all the portions of the image.

1.3 Overview of Proposed Methods

1.3.1 Definitions of Terms

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

1. *Image mosaics*: An image mosaic is obtained by arranging a large number of small images in a certain way to suggest a larger image when seen from a distance. For simplicity, we will also use the single word "mosaic" as a substitute of the term "image mosaic".
2. *Original image*: An original image is an image chosen to produce an image mosaic.
3. *Tile image*: A tile image is a small image, similar to a small specific block of the original image.
4. *Target image*: A target image is a sub-image of the original image obtained by dividing the original image into tiles. For each target image, there is a corresponding tile image to substitute in the image mosaic creation process.
5. *Cover image:* A cover image is a medium to be embedded with a watermark for copyright protection or some data for covert communication.
6. *Stego-image*: A stego-image is produced by embedding a watermark or some data into a cover image.
7. *Authentication signal*: An authentication signal is embedded into an image. It is fragile such that any alteration to the watermarked image can be detected.

8. *Division signal:* A division signal is embedded into an image for recording the information of how a secret image is divided.
9. *Reconstructed image*: A reconstructed image is obtained by composing many tile images according to the embedded division signal.
10. *Authentication image*: An authentication image is obtained by making certain indication marks in the cover image after checking the embedded authentication signals.
11. *Embedding process*: An embedding process is a process to embed data in an image.
12. *Extraction process*: An extraction process is a process to extract data from an image.

1.3.2 Brief Descriptions of Proposed Methods

In this study, we focus on dealing with full-color image mosaics, and the image formats may be BMP or JPEG. A typical framework for image mosaics creation and a related process will be given firstly. Then two data hiding techniques and a new covert communication application are proposed based on the framework. All the described data hiding methods are performed during the mosaic creation stage instead of when the mosaic is being produced.

A. Proposed Techniques for Image Mosaics Creation

In this study, a framework of image mosaics creation is described, which includes one basic system and three techniques proposed to improve the quality of the created image mosaics. The first proposed technique uses shape properties to change the appearance of tile images. Another enforces the appearance of specific tile images by an algorithm included in the composition process. The third technique alters the color distribution of tile images according to certain comparisons between tile images and target images. Figure 1.4 shows the architecture of the proposed image mosaics creation system.

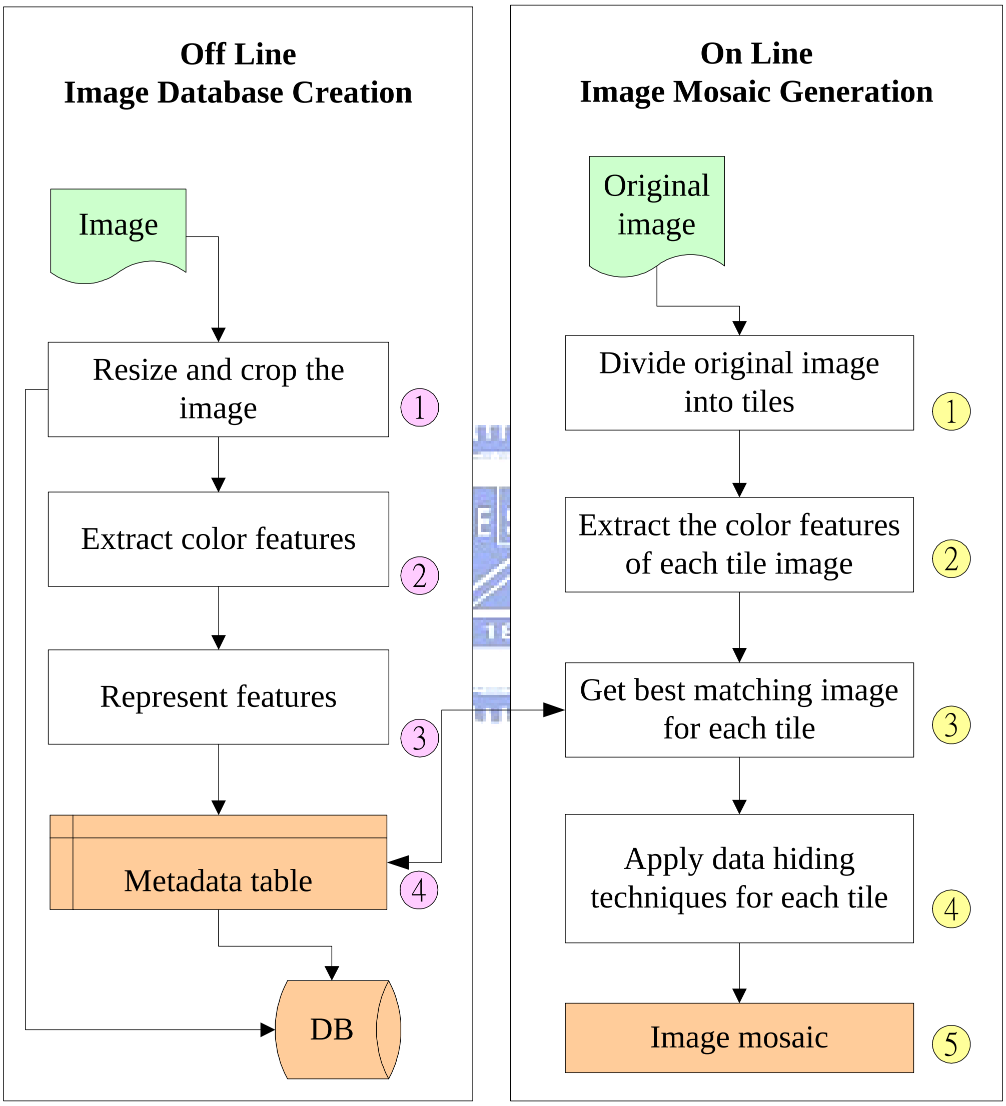


Figure 1.4 The system architecture of image mosaics.

B. Data Hiding in Image Mosaics by Visible Boundary Regions and Its Copyright Protection Application against Print-And-Scan Attacks

A method for embedding data in an image mosaic against the print-and-scan attack is proposed. The idea of this method is based on adding visible boundary regions in each tile image of an image mosaic. These visible boundary regions can be regarded as visible features, and can be detected even after the image mosaic goes through a print-and-scan process. Figure 1.5 shows a flowchart of the proposed data embedding and extracting process by adding visible boundary regions.

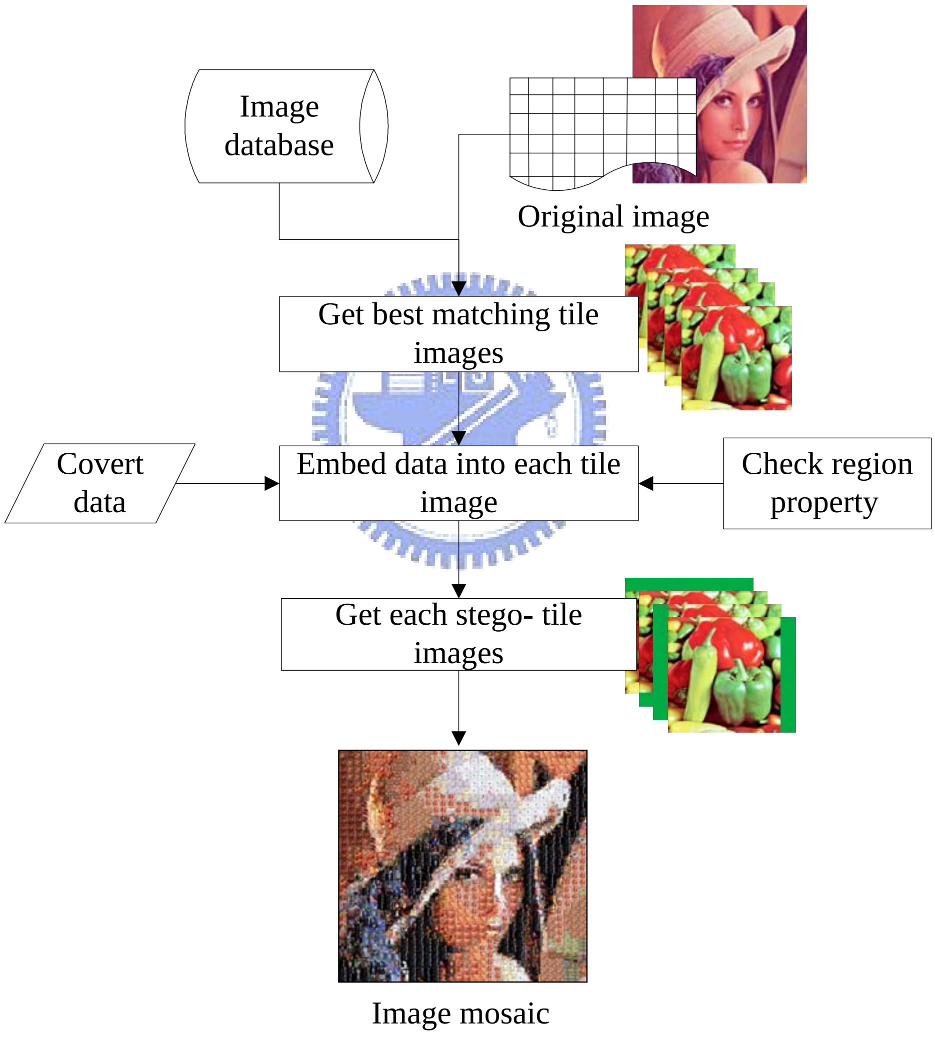


Figure 1.5 Flowchart of proposed embedding process by adding visible boundary regions.

C. Data Hiding in Image Mosaics by Histogram Modification and Its Application in Image Authentication

A method for embedding data in image mosaics with the BMP format is proposed. Authentication signals are generated and embedded by altering the pixel values of each tile images in accordance with the color histogram of the target image. By comparing extracted authentication signals with generated authentication signals, the fidelity and integrity of image mosaics can be verified. Figure 1.6 shows a flowchart of the proposed method.

D. Data Hiding in JPEG Image Mosaics and Its Application in Covert Communication

In this study, the tile images of an image mosaic are used to achieve a novel covert communication application in order to transfer a higher resolution secret image. The data hiding technique in the DCT domain is applied in the application to produce a stego-mosaic. Then the secret image will be recovered by extracting the data embedded in the stego-mosaic. Moreover, two distinct authentication processes will be presented to verify the fidelity and integrity of the image mosaic and the secret image. Figure 1.7 shows a flowchart of the proposed covert communication application using image mosaics.

1.4 Contributions

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

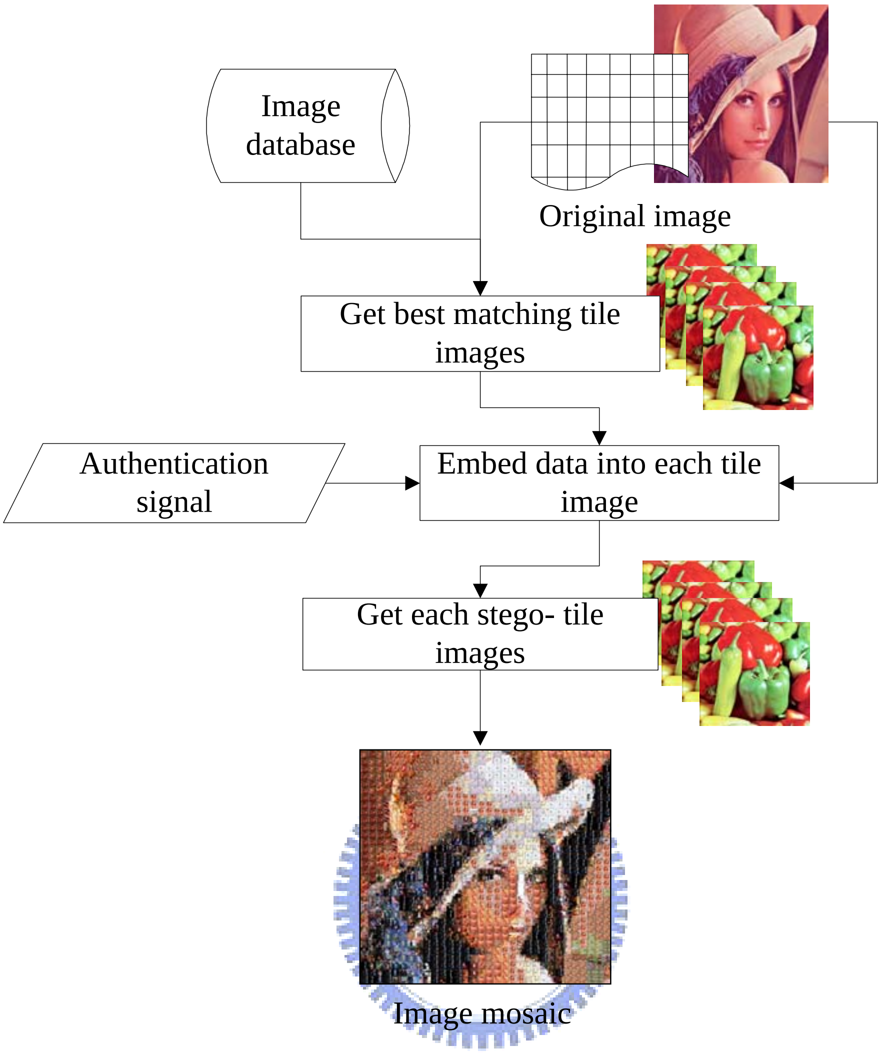


Figure 1.6 Flowchart of proposed authentication signal embedding process by histogram modification.

1. A method to generate image mosaics made of different tile shapes is proposed.
2. A method to enforce the appearance of tile images is proposed.
3. A method to adjust the colors of tile images to resemble those of the
4. corresponding target image is proposed.
5. A method to recognize the tile size of an image mosaic for tile image segmentation is proposed.

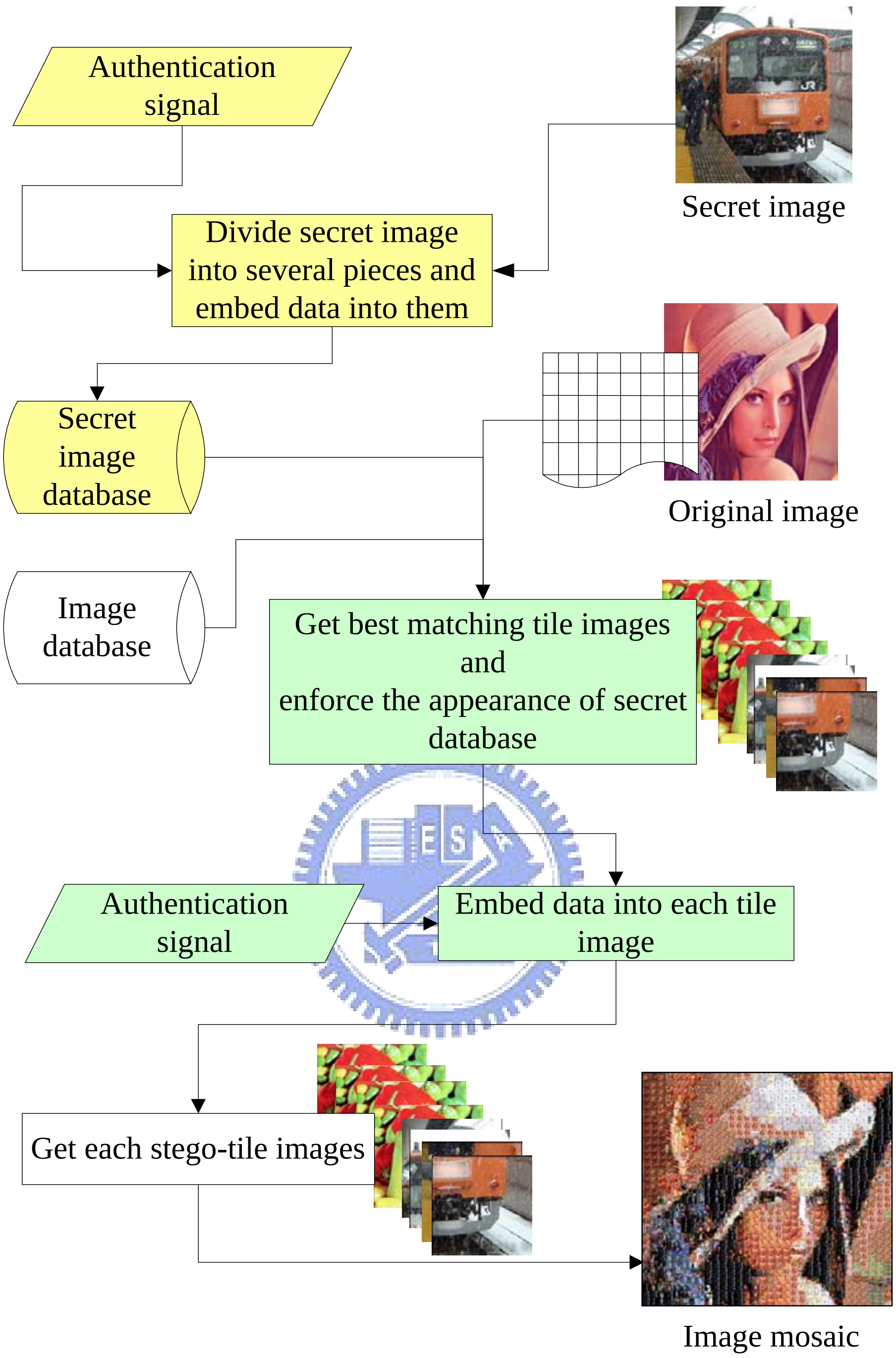


Figure 1.7 Flowchart of the covert communication application.

6. A method to detect the angle of a tilted image and re-orient it is proposed.
7. A data hiding method against print-and-scan attacks is proposed.
8. A data hiding method to embed authentication signals in image mosaics is proposed.

9. A method to verify the integrity of image mosaics as well as tile images is proposed
10. An effective integration of related techniques to conduct covert communication delivering a high-resolution secret image is proposed.
11. A new concept of double image authentication is proposed.

1.5 Thesis Organization

The remainder of this thesis is organized as follows. In Chapter 2, the proposed system for image mosaics generation and the three proposed techniques to generate image mosaics of different styles are described. In Chapters 3, 4 and 5, the three proposed data hiding techniques and their applications in image mosaics based on the system described in Chapter 2 are presented. The proposed data hiding method by the use of visible boundary regions of tile images against the print-and-scan attacks is described in Chapter 3. Chapter 4 describes a data hiding method by histogram modification to achieve image authentication. Chapter 5 includes a new covert communication application by means of image mosaics based on a DCT-domain data hiding technique. Conclusions of our works as well as discussions on future works are included in Chapter 6.

Chapter 2
Proposed Techniques for Mosaic images Creation

2.1 Introduction

Image mosaic creation is one kind of application that combines techniques in many fields, such as the use of multimedia databases, image indexing, and image retrieval. Silvers [1] proposed first a proprietary method to build image mosaics using computer technology in 1996 and Finkelstein and Range [7] described in 1998 a method to create image mosaics automatically by computers in four main steps, which include choosing a background image and a tiling grid for the mosaic style, finding a method to arrange tile images within the grid, and correcting the color distributions of the best matching tile image to resemble the corresponding target image. They also described some related perception effects of image mosaics. If an original image can be recognized easily at a very low resolution, it is good for generating an image mosaic. The study suggests that an image with more characteristics, such as famous actors, political leaders, well-known singers, etc., tends to work better than others. Furthermore, tile images with relatively uniform distributions of brightness are good in the perception of image mosaics. Then the results of a study by Ulichney [16] show that grids at 45^o are the least sensitive to the human visual system and those at 0^0 and 90^0 are the most sensitive on the contrary.

Beyond perception effects, Hunt [17] proposed two attributes of an image mosaic by experimenting with the outcomes obtained by use of different similarity measures.

The study suggests that different weights taken by the RGB channels for measuring the similarity between two images are necessary for putting emphasis on the luminance or contrast of the mosaic. For the purpose of evaluating the creation of an image mosaic, Tran [8] combined many parameters to propose a quantitative method for studying algorithms for generating image mosaics in accordance with the similarity between an image mosaic and an original image, the granularity of details in each individual tile, the variety of the selected tiles, the running time of the generation, and the number of tiles available for selection. He also proposed a method for assessing the quality of an image mosaic with respect to the original image according to the appraisals of observers. However, the proposed method is highly dependent on the subjective interpretations by observers. Zhang, Nascimento, and Zaiane [9] proposed a human-independent method which can be employed to evaluate the quality of image mosaics automatically. They experimented on the changes of the distance between an original image and two given image mosaics that are enlarged gradually. The experimental results show that the most similar one has the smallest changes of the distances.

Techniques for image retrieval and image indexing are also topics for study in the procedure of image database creation and feature extraction. The problem of searching for the most similar tile image is a topic in the content-based image retrieval field. Many methods are proposed to deal with the problem of how to index and retrieve the image according to color histograms, shape analysis, texture analysis, edge matching, and so on [18, 19, 20].

The remainder of this chapter is organized as follows. In Section 2.2, a system for creating image mosaics is described. And three techniques are proposed for use in the system in the three subsequent sections, namely, Sections 2.3, 2.4, and 2.5. Finally some experimental results are shown and discussed in Section 2.6.

2.2 Review of Traditional Image Mosaic Creation Process

2.2.1 Image Mosaics Creation Process

In previous studies, an image mosaic is built according to the following procedures. An image database is organized first prior to the mosaic creation process. The metadata of images are built through a feature extraction process and such metadata are the descriptions of the color distributions of the images. The mosaic creation process starts with an input original image and divides it into tiles based on a chosen arrangement style. A similarity measure is then employed in the process of searching the most similar tile images to the corresponding target images. Finally, after putting these tile images together, an image mosaic is produced. Figure 2.1 is the architecture of an image mosaic system and a step-by-step process is described in Algorithm 2.1 in the following.

Algorithm 2.1: ***Image Mosaic Creation Process.***

Input: an original image *I*, an image databases *DB*, and a tiling style *S*.

Output: an image mosaic *M*.

Steps.

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

Step 2. Extract the color features of each tile.

Step 3. Get from *DB* the best matching tile image for each tile according to a similarity measure.

Step 4. Compose all tile images to produce an image mosaic *M*.

Two main processes are shown in Figure 2.1, one being the image database creation process and the other the image mosaic generation process. We will describe the related works of the image mosaic system in the following section except the data hiding techniques. They will be discussed in the coming chapters, namely Chapters 3, 4, and 5.

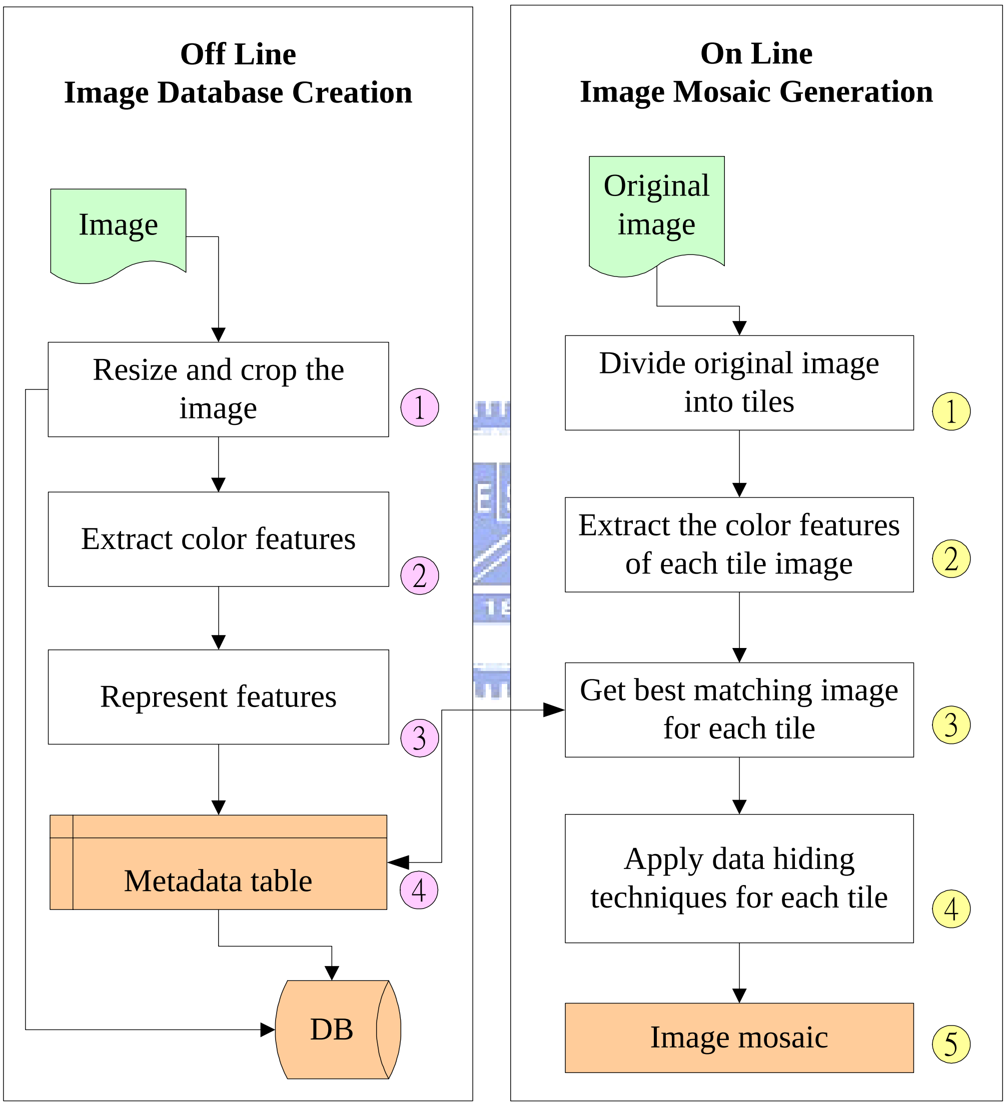


Figure 2.1 The system architecture of image mosaics.

2.2.2 Image Database Construction

The image database plays an important role in the image mosaic creation process.

It is used to accelerate the computation of searching the best matching images. The image database is built according to the following algorithm.

Algorithm 2.2: ***Image Database Construction.***

Input: an image *I*.

Output: an image *O* for use in the image database, and an associated metadata table *M*.

Steps.

Step 1. Resize and crop an image to a predefined tile size.

Step 2. Divide the image into *N* parts, where *N* is a predefined number.

Step 3. Calculate the average color of each part.

Step 4. Represent the color features as a one-dimension feature vector with *N* elements.

Step 5. Add the represented feature vector to a metadata table *M*.

Step 6. Store the resized image *O* in the storage.

In this study, an input image is first scaled to a pre-defined image size, say 128×128 pixels. In order to keep the same aspect ratio of the input image, the image is scaled until the image's width or its height reached the predefined size. That means that more often the size of the scaled image is not what we want. So a window region of the pre-defined size is chosen to be at the center of the image and the areas outside the region are cropped. This step will be of help to reduce the computational time of the mosaic creation process because the image has been scaled to a low resolution in advance. Then we divide the image obtained in Step 1 into N = 16 spatial areas as shown in Table 2.1 for feature extraction and representation. In the RGB color model, we use red, green, and blue as the three primary colors. Therefore, a feature vector for an image includes 16 triples that represent the average colors of the spatial areas. A metadata table is built by combining all the feature vectors derived in Step 4. Then the process comes to an end after saving the output image *O* in the image database.

Table 2.1 Spatial areas of an image.

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

2.2.3 Similarity Measure

The measure of the similarity between a target image and a tile image is also based on the RGB color model in this study. The input image is first divided into several spatial areas according to Step 2 of Algorithm 2.2, and a feature vector is obtained by calculating three average values of each spatial area in the RGB channels. The vector is taken an input to the similarity measure function while another input is retrieved from the metadata of the image database. An image from the image database is considered to be similar to the corresponding input image if the resulting value of the similarity measure, say an Euclidean distance, between the two feature vectors is the smallest.

Algorithm 2.3: *Similarity Measure Computation.*

Input: an input image *Target*, and a feature vector from the metadata V_{tile}.

Output: a similarity measure value *D*.

Steps.

Step 1. Divide *Target* into *N* parts, where *N* is a predefined number.

Step 2. Calculate the average color of each part.

Step 3. Represent the features as a one-dimension vector V_{target} with N elements.

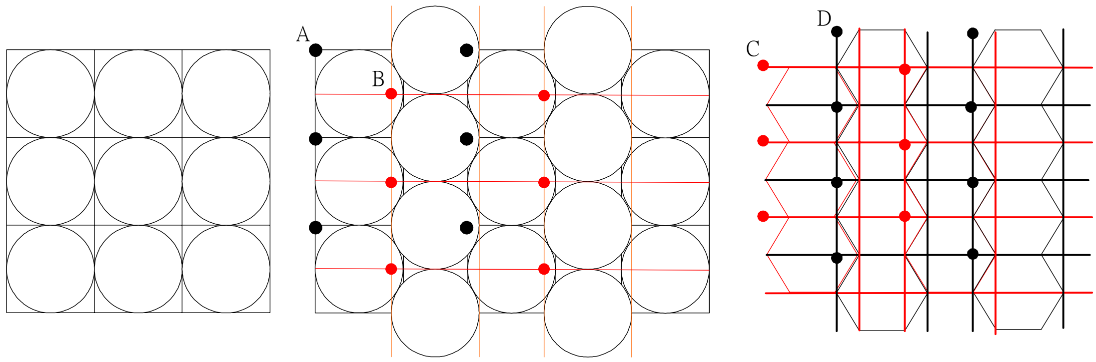
Step 4. Calculate the distance between the vector V_{target} and V_{tile} according to the following similarity measure:

$$D = \sum_{i=0}^{15} (V_{target_i} - V_{tile_i})^2 .$$

2.3 Changes of Tile Image Shapes

The impressionist painter Seurat is famous for his color-dotted paintings. In view of producing image mosaics of different styles, a method for forming tiles with dots or hexagons is proposed in this study. Once the tiles are no longer in the form of rectangle, two main problems will arise in the mosaic creation process. One is how to arrange tile images and the other is how to measure the similarities for different arrangements. Solutions to these two problems may resort to the use of different arrangement strategies with different similarity measures.

At the beginning, we solve the first problem by applying two division structures to a given original image. Two types of mosaics are formed with dots as shown in Figure 2.2. In type I, the dot-shaped tiles are arranged in a certain way just the same as rectangular tiles. However in type II, the dot-shaped tiles are arranged in particular ways that are different from previous studies. In addition, the arrangement for hexagonal tiles is also quite different from that for dot-shaped tiles.



1 2 3

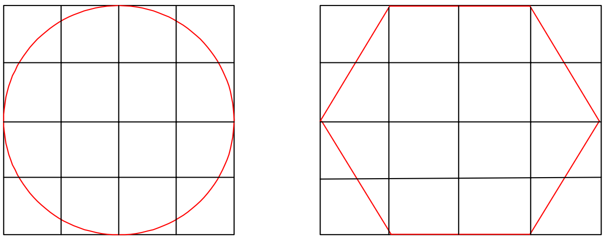
Figure 2.2 Dots and hexagons in the tiles. (1) Type I, (2) Type II, and (3) Hexagon.

A division structure is a way for dividing the image into tiles. Take Figure 2.2, for example. Figure 2.2 (1) has one kind of division structure and Figure 2.2(2), and (3) both have two kinds of division structures. The method for arranging tiles in Figures 2.2(2) or (3) is to arrange them “twice” according to the division structures. The intersections of the double arrangement in each division structure are taken as the initial points of the tiles, like points A and B shown in Figure 2.2(2), or points C and D shown in Figure 2.2(3). An initial point can be obtained by mathematical computation because the sizes of all tiles are assumed equal. In this way, target images can be derived accordingly for the purpose of measuring the similarity in the subsequent steps.

Furthermore, a weighted average method is used in this study to solve the problem of similarity measure computation because the expected target images are not rectangular any more. The weighted similarity measure applied to different shapes and computed in *Step* 4 of Algorithm 2 is the following Euclidean distance. Figure 2.3 illustrates the different shapes in a tile with 16 spatial areas and the weights in the

$$D = \sum_{i=0}^{15} W_i \times (V_{target_i} - V_{tile_i})^2.$$

above formula are obtained according to the percentage of the shape in areas. These weights are collected as a weight matrix.



1	2	2	1
2	3	3	2
2	3	3	2
1	2	2	1

1	3	3	1
2	3	3	2
2	3	3	2
1	3	3	1

1 2 3 4

Figure 2.3 The different shapes in a tile with 16 spatial areas and the weighted matrices. (1) Dot in a tile. (2) Hexagon in a tile. (3) Weighted matrix for dot-shaped arrangement. (4) Weighted matrix for hexagon-shaped arrangement.

After tile images are selected, shape properties are used for cropping images to create different tile shapes. Pixels are regarded as parts of dot-shaped tiles if their distances to the center of a dot are smaller than the radius of the given dot. And the seams between two dots are colored with the blurred color of that region of the original image. However, to generate a hexagonal tile is more complicated than to generate a dot-shaped tile. The cross product operation is usually applied to decide whether a point is inside a hexagon or not. That is, the cross product of any two vectors, which are determined by an inner pixel of the hexagon and other six nodes of the hexagon, has the same direction as that based on the *Right Hand Rule*. On the contrary, a pixel is outside the hexagon if the cross product of any two vectors, which is determined equivalent to an inner pixel, has a particular direction than those directions obtained from the other two vectors. Based on the cross product operation, the mosaic can be built with hexagons.

2.4 Enforcement of Tile Image Appearances

While creating the image mosaics, users may be interested in putting some particular images, called *constrained images*, within the image mosaics. An issue of this problem is that it is desired to include a constrained image definitely in the final image mosaic no matter what tile images with the minimum distances are selected from the image database. The way to solve the problem might be started with modifying the specific similarity measure for those constrained images or placing the top priority for the constrained images to pass the similarity measure. We take the latter idea for implementation in this study because the former one may possibly change the operations of the original image mosaic system. A top priority means the constrained image will be chosen definitely after the normal images, which are selected from the image database, have been selected through the process of the similarity measure comparison. In this way, the method can achieve the goal of the enforcement of constrained image appearances.

Two methods are proposed in this study for enforcing the appearance of constrained images. That is, to enforce the appearance of several constrained images at least one time or to enforce the appearance of one specific constrained image with expected times in the expected area. The related works are described as follows.

Algorithm 2.4: ***Enforcement of Tile Image Appearance.***

Input: a set of constrained images *C*, an original image *I*, a tiling style *S*, and a selected image database *DB*.

Output: an image mosaic *M*.

Steps.

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

Step 2. Extract the feature vector of each tile.

Step 3. Get the best matching tile image for each tile from *DB* according to the similarity measure.

Step 4. Perform the following two steps.

A. Select constrained images and place top priority on these images so that they can pass the similarity measure arbitrarily.

B. Select a specific constrained image and place it in the given region of the original image with *N* times, where *N* is a given number.

Step 5. Compose all tile images to produce an image mosaic *M*.

2.5 Adaptive Modification of Tile Image

The impression of an image mosaic results not only from the content of the image but also from the entire color of the mosaic. Within the image mosaic, because the tile images are more complicated than the target images in colors, the mosaic is not very similar to the original image. In this section, one adaptive method to modify the colors of tile images is proposed. In this study, we use the HSI color model to deal with the modification of colors. In the HSI color model, intensity is a key factor in describing color sensation and is sensitive to the human visual system. The hue describes a pure color, whereas the saturation measures the degree of how a pure color is diluted by white light [20].

However, to take into account of the distortion in image details, we have paid more attention to the hue than the intensity. The objective of the proposed method is to adjust the hue value of a pixel to make tile images more similar to corresponding target images. The problems include both what kinds of pixels require the modification and how to do that. Think that a tile image is considered dissimilar to a target image if they are evidently different in their intensity and pure color. We take this as a basis to collect all dissimilar pixels in advance. The adaptive modifications of the HSI color model are then applied according to the distance between the pixels of the tile image and those of the target image. If the distance is larger than a predefined threshold, then less modification will be applied, and vice versa. In principle, the proposed method for modification not only lets the tile image appear to be closer to the original image but also preserve the detail of the tile image. The proposed adaptive modification algorithm is described as follows.

Algorithm 2.5: ***Adaptive Modification of Tile Images.***

Input: a tile image *Tile*, and a target image *Target*.

Output: a modified tile image *Tile'*.

Steps.

Step 1. Calculate the histogram of *Tile* and *Target* in the *I* and *H* channels.

Step 2. Classify these histograms into predefined bins, say *Ibins* and *Hbins*.

Step 3. Derive the dissimilar pixels of *Tile* by the following rule:

$$if\ \ Intensity(Pixel_i^{tile}) \notin \{Intensity_{Ibins}^{target}\},\ then\ Pixel_i^{tile} \in \{Dissimilar\ \ pixels\}.$$

Step 4. Adjust the dissimilar pixels in accordance with the corresponding pixels in *Target* by two given threshold T_1 and T_2 in the following way.

A. Calculate the difference *DiffI* and *DiffS* of the intensity value and saturation value between two pixels by the following formula:

$$DiffI = Intensity(Pixel_i^{tile}) - Intensity(Pixel_i^{tar})$$
$$DiffS = Saturation(Pixel_i^{tile}) - Saturation(Pixel_i^{tar})$$

B. Assign the hue value of the pixel in the target image to the hue value of the pixel in the tile image by the following formula:

$$Hue(Pixel_i^{tile}) = Hue(Pixel_i^{tar})$$

C. If the absolute *DiffI* is larger than the threshold T_1, then modify the saturation and intensity value of the pixel in the tile image according to the following formula and a weight k:

$$Saturation(Pixel_i^{tile}) = Saturation(Pixel_i^{tile}) + k \times DiffS$$
$$Intensity(Pixel_i^{tile}) = Intensity(Pixel_i^{tile}) + k \times DiffI$$

D. If the absolute *DiffI* is larger than the threshold T_2 but smaller than the threshold T_1, then modify the saturation and intensity values of the pixel in the tile image according to the following formula and a weight t:

$$Saturation(Pixel_i^{tile}) = Saturation(Pixel_i^{tile}) + t \times DiffS$$
$$Intensity(Pixel_i^{tile}) = Intensity(Pixel_i^{tile}) + t \times DiffI$$

E. If the absolute *DiffI* is smaller than the threshold T_2, then modify the saturation and intensity values of the pixel in the tile image according to the following formula:

$$Saturation(Pixel_i^{tile}) = Saturation(Pixel_i^{tar})$$
$$Intensity(Pixel_i^{tile}) = Intensity(Pixel_i^{tar})$$

Step 5. Repeat Step 4 until all tile images has been processed.

2.6 Experimental Results and Discussion

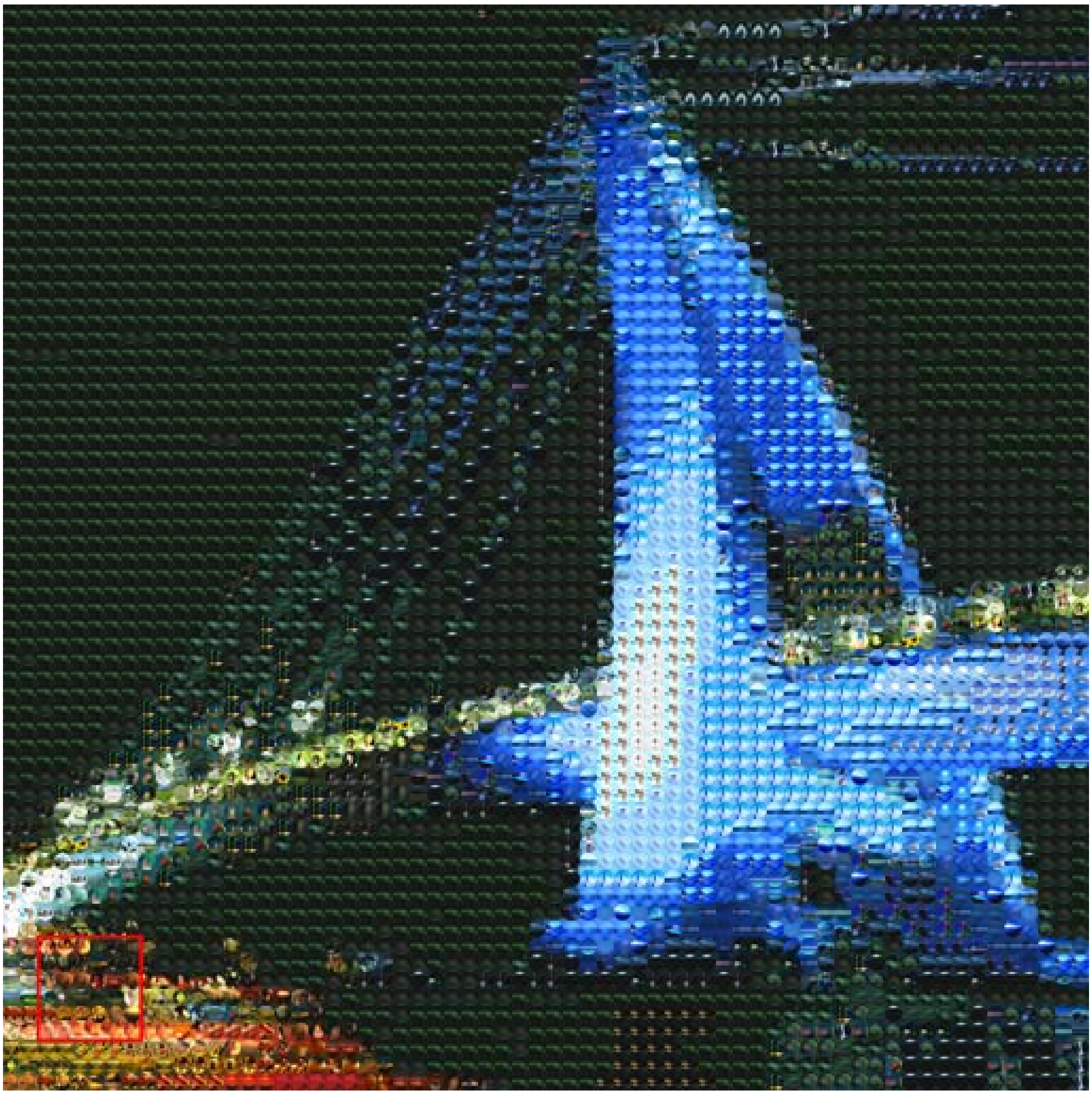
Some image mosaics generated by the proposed system using different methods are shown in this section. All the image mosaics in our experimental results are generated by the use of a database with at least 1500 tile images. The relative setups are described in company with the figures. Figure 2.4 shows one image mosaic and Figures 2.5, 2.6 and 2.7 show the results of using different tile shapes. Figures 2.8 and 2.9 show the results of our experiments on the proposed adaptive modification method.

The experimental results show that the human visual system is also sensitive to different shapes, varieties of colors, and sizes of tiles. In order to create a mosaic with a larger tile size, clearer details, and better impression, our suggestions are to collect as many as possible tile images with the same color distribution of an original image and to select the original image with many characteristics. Generally speaking, the more tile images in the image database for creating the mosaic, the better quality of the mosaic will be.

(1)

(2) (3)

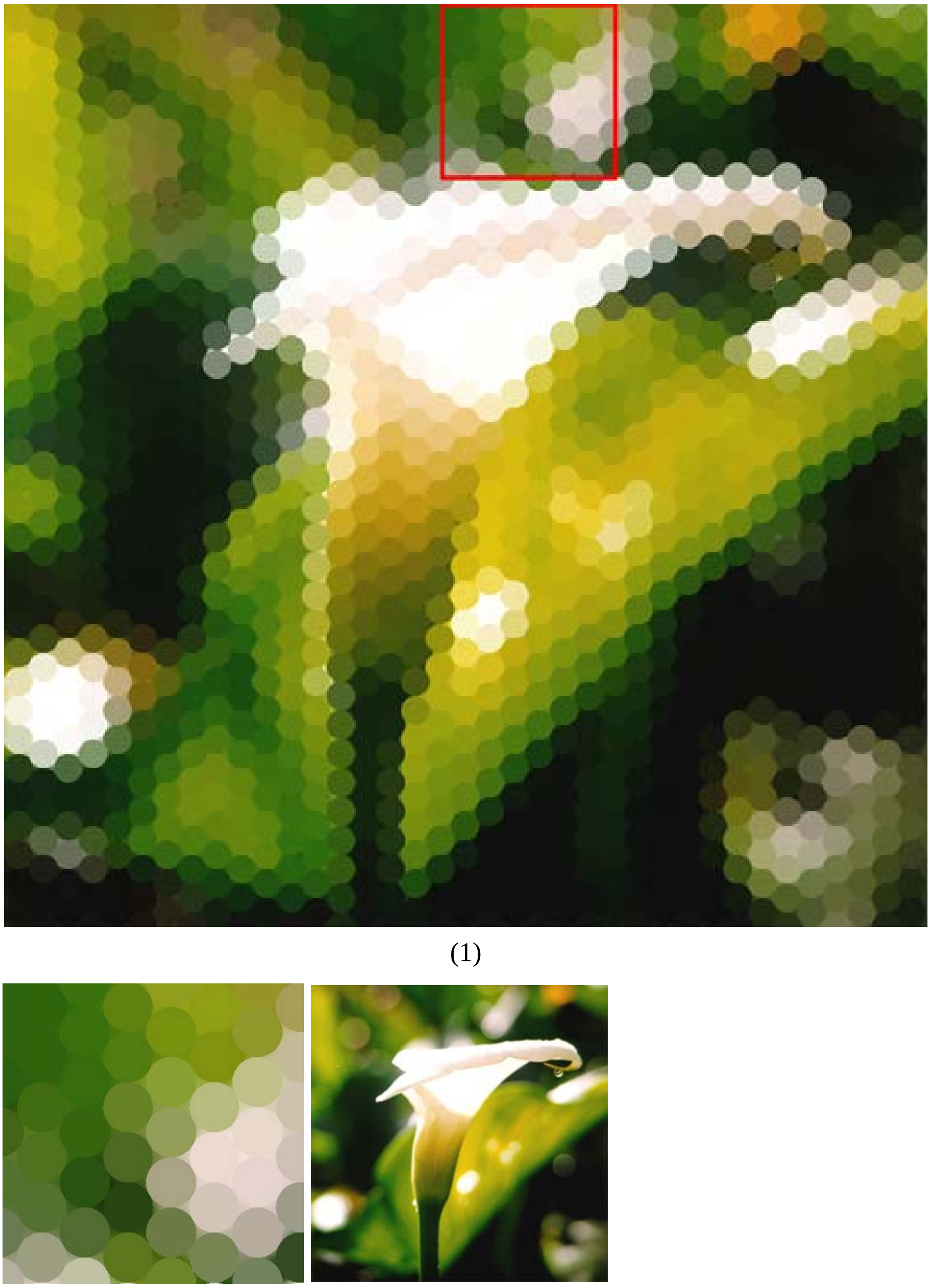
Figure 2.4 The image mosaic generated by the use of about 4000 images in the image database within 16384 blocks. (1) The image mosaic (4096×4096). (2) The tile images (32×32) of the red region. (3) The original image.



(1)

(2) (3)

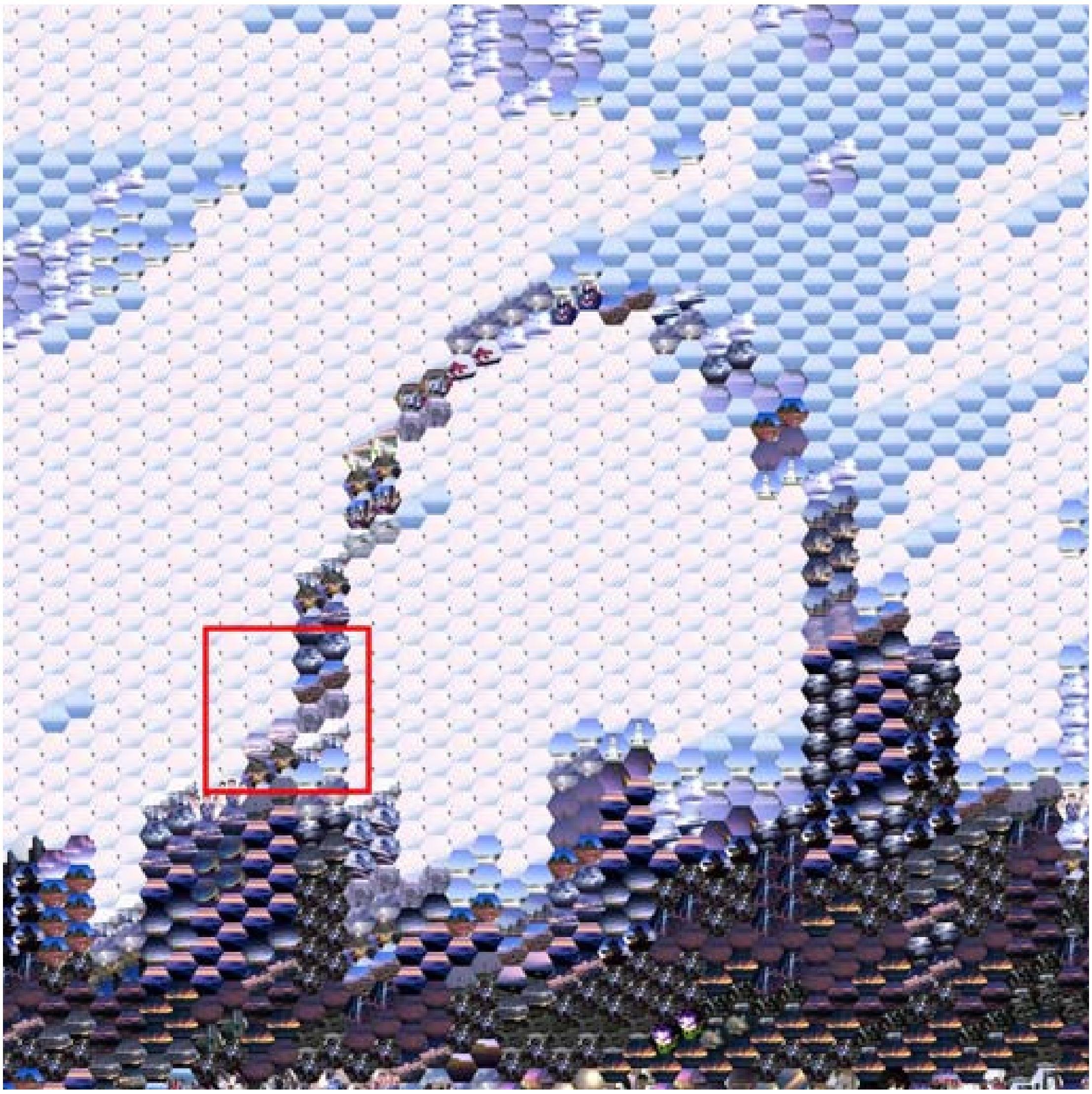
Figure 2.5 The image mosaic generated by the use of about 3000 images in the image database within 16384 Type I dot-shaped blocks. (1) The image mosaic (4096×4096). (2) The tile images (32×32) of the red region. (3) The original image.



(1)

(2) (3)

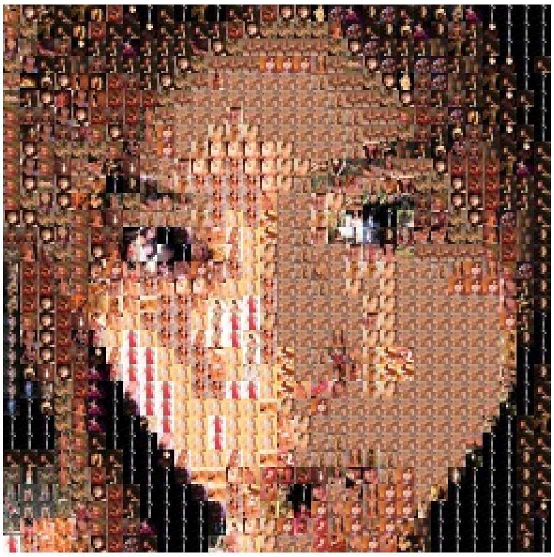
Figure 2.6 The image mosaic generated by the use of the average color within 1097 Type II dot-shaped blocks. (1) The image mosaic (2048×2048). (2) The tile color (32×32) of the red region. (3) The original image.



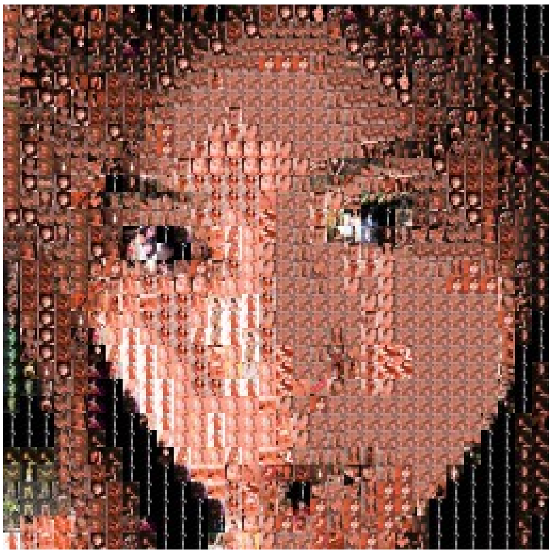
(1)

(2) (3)

Figure 2.7 The image mosaic generated by the use of about 3000 images in the image database within 2000 hexagonal blocks. (1) The image mosaic (2048×2048). (2) The tile iamge (64×60) of the red region. (3) The original image.



(1)



(2)

(3)

Figure 2.8 The image mosaic generated by the use of about 1800 images in the image database within 1024 blocks. The first one is produced without the modification. The second one has applied the adaptive modification of tile images and the numbers of the red pixels are increasing just like the original one. Notice the left side of the image (2), the region with green color is more similar to that of the original image. (1) The image mosaic. (2) The image mosaic with modification. (3) The original image.