Chapter 1
Introduction

1.1 Motivation

With the progress of science and technology, interpersonal communication is more convenient than before. When people want to transmit information to their relatives and friends at distant places, they can issue e-mails nowadays instead of conventional letters. To accomplish this, the information should be digitized and conveyed through the network. However, 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 divulging a secret, how to protect secret digital information has become an urgent issue.

Different from the traditional information protection technique, we try to hide watermarks and secret information during digital art image creation processes in this study. Since then secret information is disguised as a digital art image, people who plan to steal the information are very apt to think that the image is only an artistic exchange and then neglect it easily.

In order to integrate the aesthetic feeling and the information protection technique in this study, we will deal with three different kinds of digital art images. We name them *digital puzzle image*, *digital pointillistic image*, *and digital circular-dotted image*, respectively. Each of them will be introduced in the following chapters in detail.

1.2 Review of Related Works

1.2.1 Previous Studies on Creation of Digital Art Images

Baxter, Scheib, Lin, and DM [1] 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. They also presented a physically-based, deformable 3D brush model, which enables the users to manipulate the complex brush strokes easily. They integrated the 3D brush model with a haptic interface, with the haptic stylus taking in the position and orientation of the brush and displaying the contact force between the brush and the canvas to the user. This framework allows artists to choose a proper brush 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 1.2. Some real brushes, their model for each (skeletal structure and surface mesh), and generated examples of strokes are illustrated in Figure 1.1. The original works created using this system are shown in Figure 1.3.

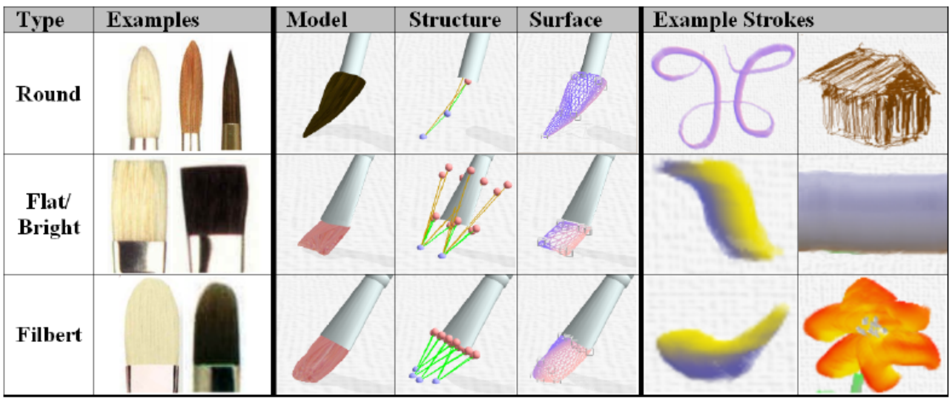
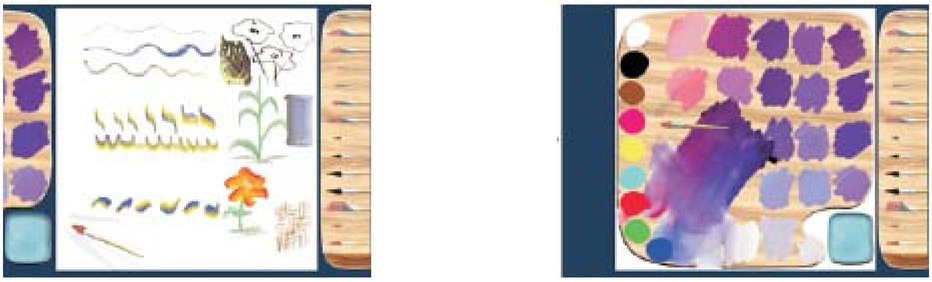


Figure 1.1 Illustration of real brushes, model for each, and example strokes generated with each [1].



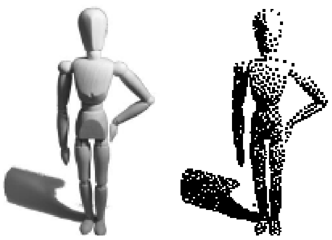
(a) (b)

Figure 1.2 Graphic user interface. (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 1.3 The original works created using the system from [1]. (a) A painting by Rebecca Holmberg, artist. (b) A painting by Andrei State, artist.

Different from the semi-automatic digital art image creation system proposed in [1], many researches investigated the problem of how to create digital art images automatically in recent years. We show some experimental results in Figure 1.4. Figure 1.4(a) is an image created by a weighted voronoi stippling algorithm from Secord [2]. Figure 1.4(b), (c), and (d) are created from Secord [3]. Figure 1.4(b) is a hatched pen-and ink illustration using the image gradient for primitive orientation. Figure 1.4(c) is a tiger model hatched with large strokes to achieve a furry look. Figure 1.4(d) is a bunny model hatched with curved strokes. Figure 1.4(e) is another pen-and-ink drawing created from [4]. Figure 1.4(f) is created form Haeberli [5]. Figure 1.4(g) is an embossed painting created from Hertzmann [6]. The height field is computed by rendering every brush stroke with a height texture, and used for lighting the surface of the painting. Figure 1.4(h) is created from Hertzmann [7]. Figure 1.4(i) is a computer-generator watercolor from [8]. Various painterly renderings of a pink flower was shown in Figure 1.4(j) [9], in which there are “watercolor”, “Van Gogh”, “Impressionism”, “Abstract”, “Pointillism”, “Flower”, “Abstract” styles. Figure 1.4(k) illustrated the original stained glass and a visual simulation of ice crystal growth on a stained glass window [10]. Figure 1.4(l) illustrated the visual simulation of light refracting through a stained glass window [10].



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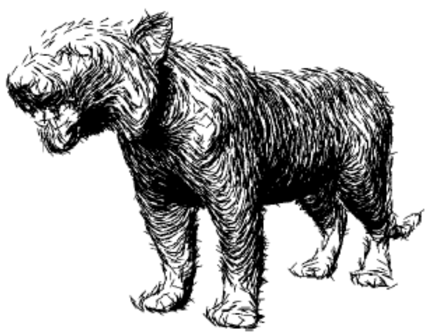


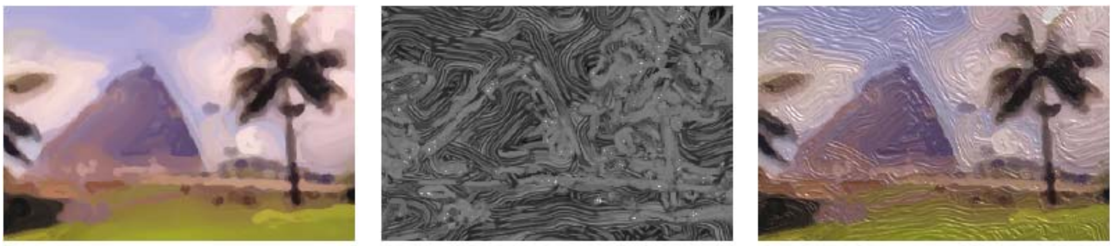
(c)

(d)

Figure 1.4 Samples of computer-generator art images. (a) An image created from Secord [2]. (b), (c), and (d) are images created from Secord [3]. (e) Another pen-and-ink drawing created from [4]. (f) An image created form Haeberli [5]. (g) An embossed painting created from Hertzmann [6]. (h) An image created from Hertzmann [7]. (i) A computer-generator watercolor from [8]. (j) Images created from [9]. (k) The original stained glass and a visual simulation of ice crystal growth on a stained glass window [10]. (l) The visual simulation of light refracting through a stained glass window [10].

(e)

(f)



(g)

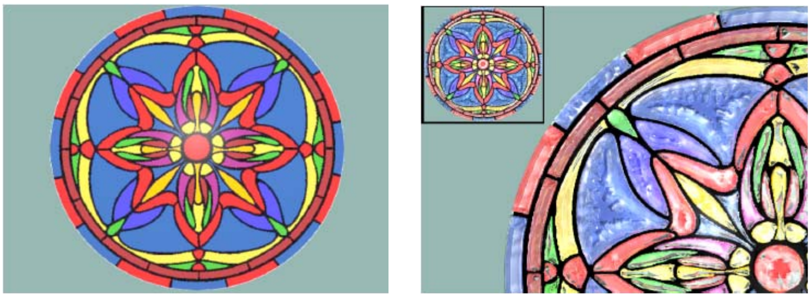
Figure 1.4 Samples of computer-generator art images. (a) An image created from Secord [2]. (b), (c), and (d) are images created from Secord [3]. (e) Another pen-and-ink drawing created from [4]. (f) An image created form Haeberli [5]. (g) An embossed painting created from Hertzmann [6]. (h) An image created from Hertzmann [7]. (i) A computer-generator watercolor from [8]. (j) Images created from [9]. (k) The original stained glass and a visual simulation of ice crystal growth on a stained glass window [10]. (l) The visual simulation of light refracting through a stained glass window [10]. (continued).

(h)

(i)

(j)

Figure 1.4 Samples of computer-generator art images. (a) An image created from Secord [2]. (b), (c), and (d) are images created from Secord [3]. (e) Another pen-and-ink drawing created from [4]. (f) An image created form Haeberli [5]. (g) An embossed painting created from Hertzmann [6]. (h) An image created from Hertzmann [7]. (i) A computer-generator watercolor from [8]. (j) Images created from [9]. (k) The original stained glass and a visual simulation of ice crystal growth on a stained glass window [10]. (l) The visual simulation of light refracting through a stained glass window [10]. (continued).



(k)

(l)

Figure 1.4 Samples of computer-generator art images. (a) An image created from Secord [2]. (b), (c), and (d) are images created from Secord [3]. (e) Another pen-and-ink drawing created from [4]. (f) An image created form Haeberli [5]. (g) An embossed painting created from Hertzmann [6]. (h) An image created from Hertzmann [7]. (i) A computer-generator watercolor from [8]. (j) Images created from [9]. (k) The original stained glass and a visual simulation of ice crystal growth on a stained glass window [10]. (l) The visual simulation of light refracting through a stained glass window [10]. (continued).

1.2.2 Previous Studies on Creation of Digital Mosaic Images

Kim and Pellacini [13] surveyed the ideas of creating *jigsaw image mosaics* (JIM). A jigsaw image mosaic algorithm designed by them takes as input an arbitrarily-shaped *container image* and a set of image tiles of arbitrary shapes as shown in Figure 1.5(a) and generates a mosaic as shown in Figure 1.5(b). In order to efficiently compute a jigsaw image mosaic, they proposed an effective algorithm organized in three phases as shown in Figure 1.6. In the first phase, they chose and roughly placed the tiles, ignoring deformation. In the second phase, they refined the placement of each tile and deformed them if necessary. Finally, they assembled the final mosaic by placing each tile in its position and warping each image to its final deformed shape using a warping technique.

Simulated Decorative Mosaics from Hausner [12] is an algorithm that can generate tile mosaics. Photomosaics from Silvers and Hawley [11] is a different kind of mosaic where a collection of small images is arranged in a rectangular grid. When viewing the resulting image mosaic from a distance, the small images combine to yield an impressive integrated painting. A comparison of the images obtained by the three algorithms is presented in Figure 1.7.

Figure 1.5 Jigsaw image mosaic (JIM) created by Kim and Pellacini [13].

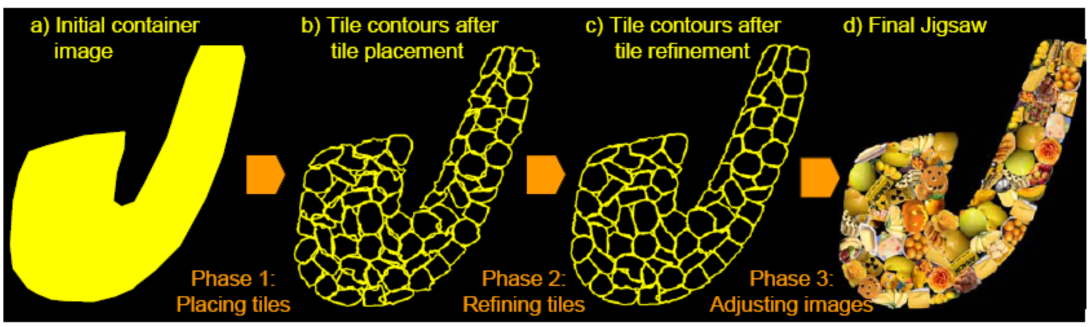


Figure 1.6 Phases of jigsaw image mosaics algorithm.

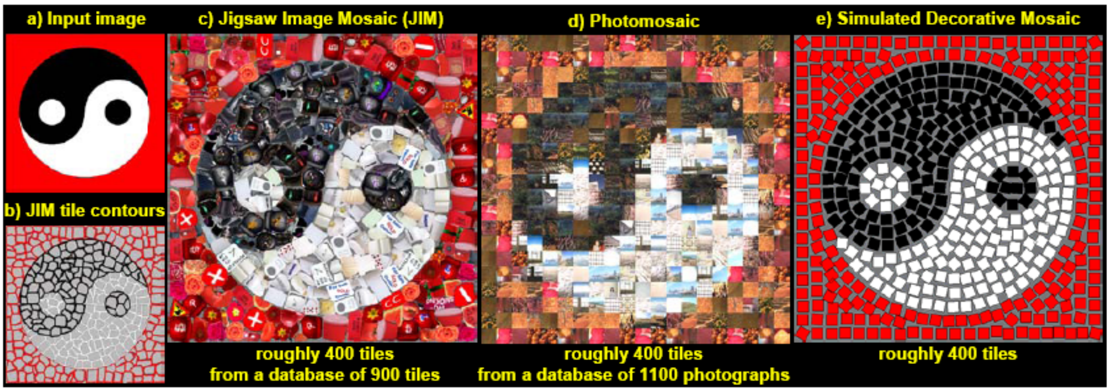


Figure 1.7 (c) An image from Kim and pellacini [13]. (d) An image from Silvers and Hawley [11]. (e) An image from Hausner [12].

1.2.3 Previous Studies on Jigsaw Puzzles Reconstruction Process

Automatic solution of jigsaw puzzles by shape alone goes back at least to 1964 [14], and numerous papers have been written on this subject since then. Papers on this subject traditionally justify the work by citing related problems. Related problems include reconstructing archeological artifacts [15, 16], mating surface patches of scanned objects [18], and even fitting a protein with amino acid sequence to a 3D electron density map [18]. However, the real interest in jigsaw puzzle solving is simply that it is a natural and challenging problem.

David, Christopher, and Marshall [20] presented an algorithm for automatically solving jigsaw puzzles by shapes alone. They can handle puzzles in which pieces border more than four neighbors, and puzzles with as many as 200 pieces. The proposed algorithm follows the same overall approach as that of Wolf-son et al. [19], that is, first solving the border and then filling in interior “pockets,” but their algorithm make more use of global geometry. Without the use of backtracking or branch-and-bound, their algorithm applies a number of new ideas, such as robust fiducial points, "highest-confidence-first" search, and frequent global reoptimization of partial solutions. They used two jigsaw puzzles purchased at the toy store: a 100-piece puzzle made by Milton-Bradley as shown in Figure 1.8, and a 204-piece puzzle made by Ravensburger as shown in Figure 1.9. The puzzle pieces are about a millimeter thick and cast shadows when scanned. They extracted the pieces from the scans, and started to assemble them back by computer.

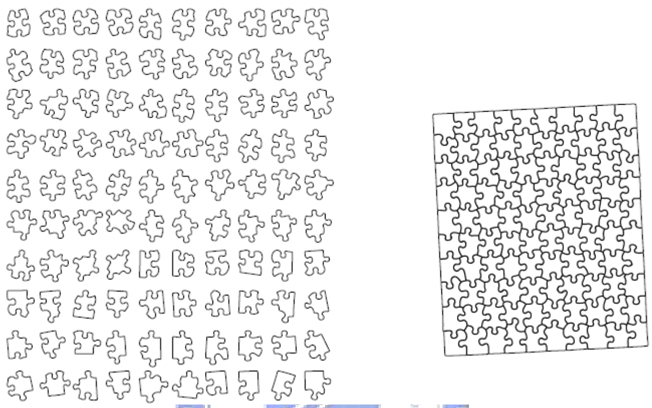


Figure 1.8 This 100-piece puzzle presents a difficulty for previous algorithm: pieces do not have four-well defined sides.

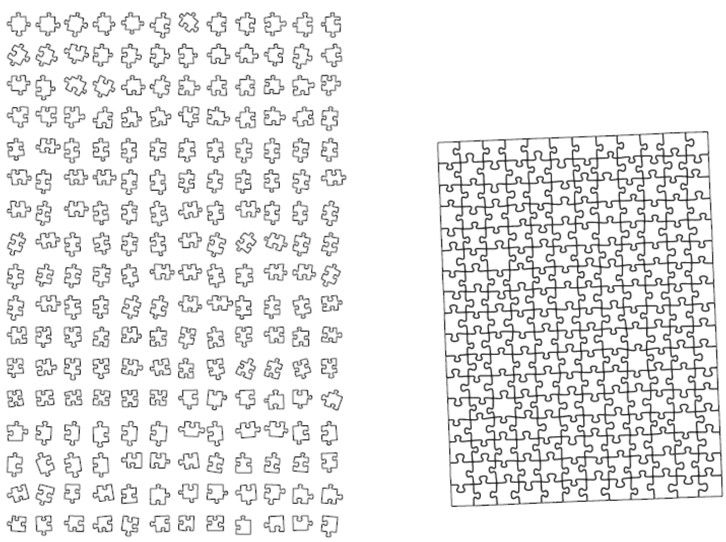


Figure 1.9 This 204-piece puzzle is the largest one solved automatically to date [20]. Wolfson et al. [19] solved two intermixed 104-piece puzzles, but the two-puzzle problem is somewhat easier because there is more border and near-border.

1.2.4 Previous Studies on Information Hiding

The main purpose of information hiding is to embed information imperceptibly into a given media. In principle, information hiding in images aims at the weakness of the human visual system, for example, by changing the least significant bits of the pixels of a cover image to embed information [21]. 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, or implement the secret sharing concept via an image, and so on.

Information hiding in images is a popular research topic in recent years. Researches on this topic can be classified into three approaches, which are the spatial-domain approach, the frequency-domain approach, and the combination of the two [22]. No matter what types they belong to, most of these researches are based on pixelwise or blockwise operations. In this study, unlike the traditional methods of information hiding in images described before, we will hide data in the orientations, sizes, and angles of digital puzzle images, and hide data by modifying the RGB values of the dots in digital pointillistic images or by deciding the drawing order of the circular dots in digital circular-dotted images. Besides, we also implement the concept of information sharing by separating a digital puzzle image into several digital puzzle pieces. All the details will be discussed in the following chapters.

1.2.5 Previous Studies on Data hiding in Art Images

Lin and Tsai [23, 24] proposed a method to hide information in image mosaics (or photomosaics) by manipulating the four borders and the histogram of a tile image. Hung and Tsai [25] proposed two methods to hide information in art images. One is to embed data in tile mosaic images by modifying the orientations, sizes, and textures of tile mosaic images. The other is to embed data in stained glass images by slight glass cracking.

All of these researches have implemented the concept of integrating the methods for art image creation and data hiding. Some image mosaics created by Lin and Tsai [23, 24] are presented in Figure 1.10. Some tile mosaic image and the stained glass image created by Hung and Tsai [25] are shown in Figure 1.11.


(a)

(b)

Figure 1.10 Image mosaics created by Lin and Tsai [25, 26]. (a) An image mosaic of Lena. (b) An image mosaic of Albert Einstein.

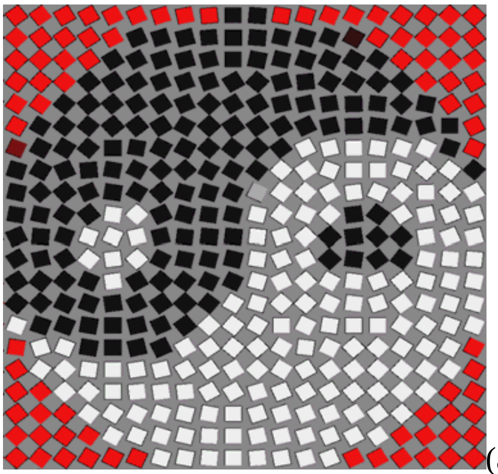

(a)

Figure 1.11 Art images created by Hung and Tsai [27]. (a) A tile mosaic image. (b) A stained glass image.


(b)

1.3 Overview of Proposed Methods

1.3.1 Definitions of Terms

Before describing the proposed methods, some definitions of the terms used in this study are introduced as follows.

1. *Original image*: an original image is an image chosen to produce a digital puzzle image, a digital pointillistic image, or a digital circular-dotted image.
2. *Digital art image*: a digital art image is a non-photorealistic image created from an original image. In this study, an art image may be a digital puzzle image, a digital pointillistic image, or a digital circular-dotted image.
3. *Digital puzzle image*: a digital puzzle image is an image composed of several digital puzzle pieces.
4. *Digital Pointillistic image*: a digital pointillistic image is an image created by imitating the style of the pointillistic painter via a computer.
5. *Digital circular-dotted image*: a digital circular-dotted image is an image composed of numerous randomly overlapped small circular dots with black borders.
6. *Embedding process*: an embedding process is a process to embed data in a digital art image.
7. *Extraction process*: an extraction process is a process to extract hidden data from a digital art image.
8. *Digital puzzle image separation process*: a digital puzzle image separation process is a process to separate a digital puzzle image into several digital puzzle pieces.
9. *Digital puzzle image reconstruction process*: a digital puzzle image

reconstruction process is a process to search the separated digital puzzle pieces and assemble them back via a computer automatically.

10. *Authentication signal*: an authentication signal is embedded into an digital art image. It is fragile such that any alteration to the image can be detected.
11. *Authentication image*: an authentication image is obtained by making certain indication marks in the cover image after checking the embedded authentication signals. By the indication marks, people are aware of which parts of the cover image have been tampered with.

1.3.2 Brief Descriptions of Proposed Methods for Creation of and Information Hiding in Digital Puzzle Images

The proposed process of data hiding in a digital puzzle image is shown in Figure 1.12. According to the flowchart, first of all, we create a digital puzzle image by a creation process proposed in this study, which will be discussed thoroughly in Chapter 2. Second, we transform the given data into a bit sequence. The given data might be a watermark, secret information, or any digital data which you want to transmit covertly. Each of them will be embedded into three parameters of the digital puzzle image individually and simultaneously. Certainly, it does not mean that all the three kinds of information should be hidden at the same time. We can embed only one or two of them by choice. A detailed discussion of information hiding in digital puzzle images will be stated in Chapter 3.

After a puzzle image has been created and the secret information has been embedded successfully in it, we start to perform the information sharing process, which includes a digital puzzle image separation process proposed in Section 2.2.2.2 and a digital puzzle image reconstruction process proposed in Section 2.3. A flowchart of the proposed information sharing process is shown in Figure 1.13.

After the puzzle image has been recovered, we begin to extract the embedded data as the flowchart shown in Figure 1.14 illustrates. First, we perform the digital puzzle piece feature detection techniques proposed in Section 3.2. Second, we perform the data extraction process discussed in Section 3.3 through Section 3.5 after checking the input secret key, and we finally extract the secret information from the digital puzzle image.

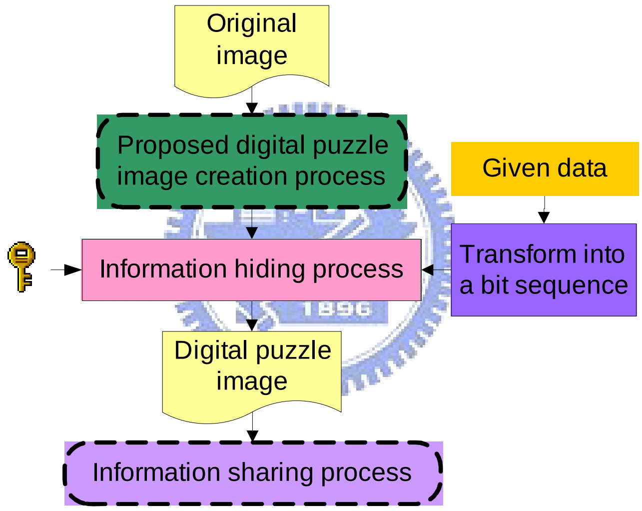


Figure 1.12 Proposed process of information hiding in a digital puzzle image.

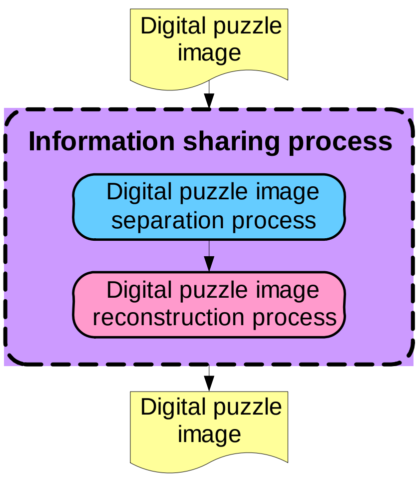


Figure 1.13 Proposed process of information sharing.

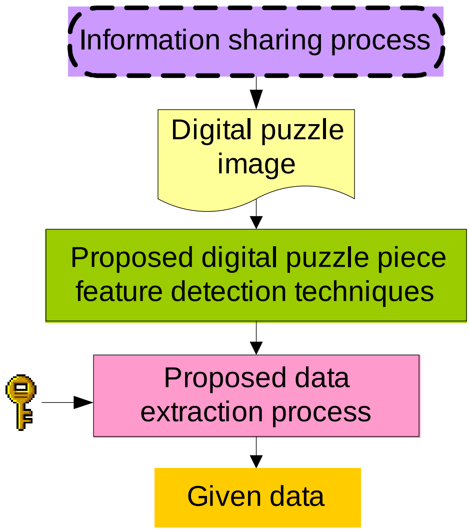


Figure 1.14 Proposed process of data extraction from a digital puzzle image.

1.3.3 Brief Descriptions of Proposed Methods for Creation of and Information Hiding in Digital Pointillistic Images

The proposed process of data hiding in a digital pointillistic image is shown in Figure 1.15. This process is similar to the one for digital puzzle images, but the timing of using a secret key is different. After transforming the given data into a bit sequence, we utilize a secret key to disarrange the order of it before executing the information hiding process in a digital pointillistic image.

The data extraction process is an inverse version of the information hiding process as shown in Figure 1.16. After executing the data detection and extraction process, we get a disordered sequence of data. And then as the last step, we utilize a secret key to recover the data in its original order. A detailed discussion of the information hiding and extraction process for digital pointillistic images will be stated in Chapter 4.

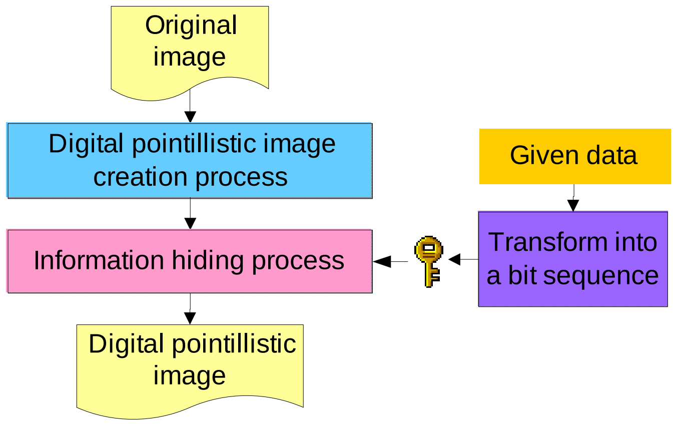


Figure 1.15 Proposed process of data hiding in a digital pointillistic image.

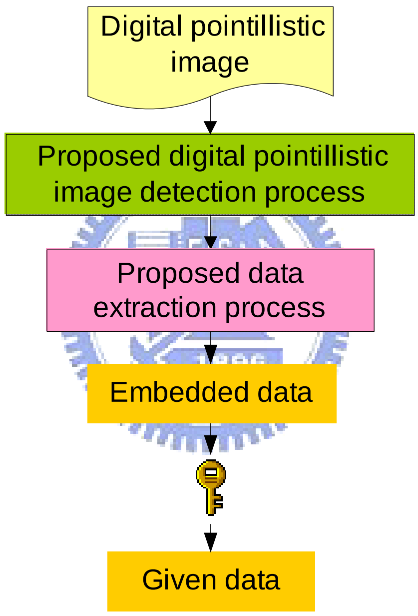


Figure 1.16 Proposed process of data extraction from a digital pointillistic image.

1.3.4 Brief Descriptions of Proposed Methods for Creation of and Information Hiding in Digital Circular-dotted Images

The process of data hiding in a digital circular-dotted image is illustrated in

Figure 1.17. The data extraction process is an inverse version of the data hiding process as shown in Figure 1.18. These data hiding and extraction processes for digital circular-dotted images are similar to those for digital pointillistic images, but the information hiding processes of them are totally different. For example, we achieve the purpose of data hiding by changing the RGB values of the center of each colorful dot in a digital pointillistic image, but we achieve this purpose by applying the dot overlapping scheme proposed in Section 5.3.2 to control the drawing order of the circular dots in a digital circular-dotted image. Detailed descriptions of the proposed methods shown in these two flowcharts will be given in Chapter 5.

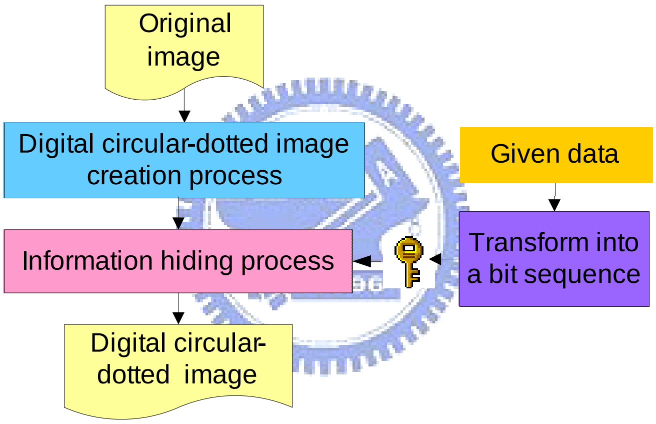


Figure 1.17 Proposed process of data hiding in a circular-dotted image.

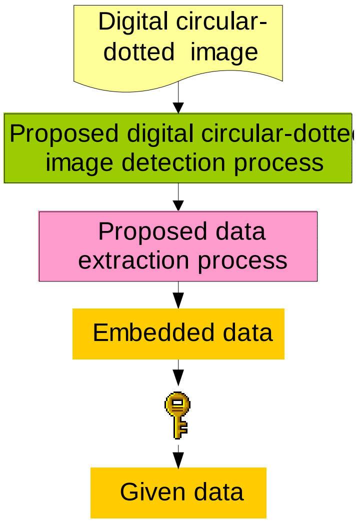


Figure 1.18 Proposed process of data extraction from a circular-dotted image.

1.3.5 Contributions

Some major contributions of this study are listed as follows.

1. A method to create digital puzzle images by boundary shape parameterization is proposed.
2. A method to hide information in the orientation, size, and angle of a digital puzzle piece in a digital puzzle image is proposed.
3. A method to detect the orientation, size, and angle of a digital puzzle piece in a digital puzzle image is proposed.
4. Methods to embed secret information, watermarks, and authentication signals, respectively, into the orientations, sizes, and angles of the digital puzzle pieces in a digital puzzle image are proposed.
5. A method for digital puzzle image decomposition for information sharing is proposed.
6. A method for digital puzzle image reconstruction is proposed.
7. A method to create digital pointillistic images is proposed.
8. A method to hide data in the color of a dot by a palette color coding technique is proposed.
9. A method to detect the color of a dot by a palette color coding technique is proposed.
10. Methods to embed secret information and watermarks simultaneously into the colors of dots in a digital pointillistic image are proposed.
11. A method to create circular-dotted images is proposed.
12. A method to hide data in the drawing order of the overlapped circular dots in a digital circular-dotted image is proposed.
13. A method to detect the order of overlapped circular dots is proposed.

14. Methods to embed secret information and watermarks simultaneously into the drawing order of the overlapped circular dots in a digital circular-dotted image are proposed.

1.4 Thesis Organization

This thesis is organized as follows. In Chapter 2, the proposed system of digital puzzle image creation by boundary shape parameterization for information hiding, and the proposed method of digital puzzle image separation and reconstruction for information sharing are described. In Chapter 3, the proposed information hiding methods by utilizing the three features of puzzle pieces will be introduced. The three corresponding applications (i.e. watermarking, secret communication and authentication) and the proposed puzzle piece feature detection are also discussed in Chapter 3. Chapter 4 describes the proposed digital pointillistic image creation method. The proposed dot color detection process and the data hiding method by a palette color coding technique are also described. In Chapter 5, the proposed digital circular-dotted image creation method and the proposed data hiding method by utilizing a dot overlapping scheme in a digital circular-dotted image are discussed. Conclusions of our works as well as discussions on future works are included in Chapter 6.