Halftone information hiding technology based on phase feature of space filling curves

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Abstract. To solve the problems of the production of interference fringes (namely moiré in printing) and improve the image quality in printing process of halftone screening for information hiding, a halftone screening security technique based on the phase feature of space filling curves is studied in this paper. This method effectively solves the problem of moire and optimizes the quality of the screening, so that the images presented after screening have achieved good visual effect. The pseudo-random scrambling encryption of the plaintext information and the halftone screening technique based on the phase feature of the space filling curves are carried out when screening which not only eliminates the common moire in the screening but also improves the image quality and the security of information.

1. Introduction
Information hiding of halftone screening technique via using the non-perceivable ability of human eye on the tiny dots, screening the main map of the printing color separation, introducing hidden information and graphs in a color version or a few color plate and changing the dots location of the graphic hidden selection area, the purpose of information hiding has been achieved [1]. With the vigorous development of graphic information rasterization technology, information hiding in halftone screening has become the hotspot in today's research. Although there are many ways to solve the information hiding in the halftone screening, the general screening in the dots shape and its arrangement which has strong regularity make the screened image easily produce moire and affect image reproduction effect [2]. In this paper, the halftone screening and information hiding method based on the phase feature of space filling curves are presented. The hidden graphic information is characterized by different dot morphological templates and embedded in pseudo-random scrambling way, so that the problems of the prevalence of moire in the screening and the low image quality and so on were solved. This method has achieved ideal effect in information hiding and information anti-counterfeiting and so on.

2. Halftone Screening Based on Phase Feature of Space Filling Curves
In the traditional halftone screening, halftone screening is divided into amplitude modulation (AM) screening and frequency modulation (FM) screening. The amplitude modulation screening is the binarization of the image using different dots size, and the size of the dots corresponds to the corresponding gray value in the original image. Because of the regularity of its arrangement, the halftone image after screening has obvious moire, and the amplitude modulation algorithm is to control the gray scale of the image with the dots size, this leads to the fact that there is a large distortion in the bright and dark regions. To solve this problem, but also put forward the FM screening. FM dots size are fixed, which is through the control the intensity of the dots to show the tone, relative to the amplitude modulation can better prevent the occurrence of interference fringes, and the performance of the tone closer to the original continuous tone image. However, FM screening will
cause the problem of dots expansion, which seriously affected the image reproduction effect. Moreover, it is difficult to popularize in the practical application because of the higher requirements of some materials and machines. Halftone screening based on phase feature of space filling curves is overcome the above problems, it not only avoided the production of moiré, but also reduced the process requirements.

2.1. Space Filling Curves
Space filling curves[3] (SFC) were first discovered by the Italian mathematician Giuseppe Peano in 1890 for mapping from one-dimensional space to higher dimension, it is classified into fractal mathematical set because of its self-similarity, which is defined as follows:

Make a mapping c as

\[ c : I \rightarrow R^2 \mid I = [0,1], R^2 = \{(x, y); x, y \in R\} \]

Then space filling curve is a mapping c covering the unit space \( S^2 = [0, 1] \times [0, 1] \). For each point P in S there is a real number t, so that \( c(t) = P \). When \( t \) is changed from 0 to 1, the map c provides the order of each point in the access space, that is, every point in the plane can be represented by a space filling curve on a continuous line \((0,1)\)[4].

There are many forms of space filling curves. Following Giuseppe Peano, mathematicians Hilbert (1891) and Sierpinski (1912) also constructed different types of space filling curves. The typical space filling curves approximation are shown in Figure 1:

![Space Filling Curves](image)

(a) Peano  (b) Hilbert  (c) Sierpinski

**Figure 1.** Typical space filling curves.

From the three space filling curves shown above, they all have the ability to access all the pixels, the only difference in traversing the path of the pixels, which are the value of the curves. Since the pixel arrangement of the digital image has a rectangular feature, the space filling curves are easier to traverse each pixel.

The most typical space filling curves are the Giuseppe Peano curve and the Hilbert curve. As the space filling curves have self-similarity, the Hilbert curve is taken as an example, as shown in Figure 2, (a) is the primitive of the Hilbert curve; (b) is the subunit, the four primitives are arranged in the order of four points in the primitive. In this way, the whole Hilbert curve is formed. The same is true of the Peano curve, which is easily achieved in recursive language. However, the space filling curves must occupy a square, such as the Hilbert curve occupied by the size of the area \( 2n \times 2n \), Peano curve of \( 3n \times 3n \). And the image is not necessarily just so big, especially when the image length and width difference is very large, the image must be divided into several small pieces, according to the order of the curve were dealt with separately [5-8].
2.2. Screening Process
In this experiment, we first make a continuous image by multi-level quantization and error diffusion processing to make it a multi-level gray-scale image, and then call the halftone template to modulate the multi-level gray image and make it a secret halftone image. Before modulation, we need to standardize the information to be standardized, spread spectrum, scrambling and other processing, the specific flow chart is shown in Figure 3.

![Figure 2. Hilbert curve.](image)

![Figure 3. Screening process.](image)

2.3. Error diffusion
In this experiment, the multi-value quantization is the original 256 levels of gray scale quantization to 16 grayscale, that is, the original image of the gray value becomes 0 to 15. From 256 gray to 16 grayscale, will naturally compress the details, resulting in errors. Therefore, we need to spread the original image error in order to better restore the original picture details.

In the colour conversion process of the image, due to the different color range, the conversion process may produce errors, the quantization error of the current pixel is spread to adjacent pixels in a certain proportion so the local quantization error is compensated on adjacent pixels [9, 10]. The basic processing consists of three steps, first, the pixel value of the original gray scale image at that point is added to the error value previously diffused there, and as a result of the current input; second, the current input value and the threshold is compared to get a binary output, the third, the input value and the output value of the error in accordance with a certain law spread to the untreated area. The block diagram of the error diffusion algorithm is shown in Figure 4:
Figure 4. Principle block diagram of error diffusion algorithm.

The mathematical model corresponding to the error diffusion algorithm is:

\[ g(m,n) = f(m,n) + \sum_{k,l} w(k,l) \cdot e(m-k,n-l) \]

\[ b(m,n) = Q[g(m,n)] = Q[f(m,n) + \sum_{k,l} w(k,l) \cdot e(m-k,n-l)] \]

\[ e(m,n) = b(m,n) - g(m,n) \]

\( H(m,n) \) is the error filter, \( f(m,n) \) is the pixel value of the input image pixel, \( e(m,n) \) is the quantization error value, \( w(k,l) \) is the coefficient of the filter, \( b(m,n) \) is the output pixel value.

2.4. Spread Spectrum Algorithm

Spread spectrum communication is an information transmission method, the spectrum is the frequency domain description of the electrical signal, and the spectrum carrying various information (such as voice, image, data, etc.) are generally represented in the time domain, that is, the information signal can be expressed as a function of time \( f(t) \). The frequency domain representation \( F(f) \) can be obtained by Fourier transform in its time domain representation \( f(t) \) of the signal. The relationship between frequency domain and time domain is determined by equation (1-1):

\[ F(f) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j2\pi ft} dt \]

\[ f(t) = \int_{-\infty}^{\infty} F(f) \cdot e^{j2\pi ft} df \]

The sufficient condition for the existence of the Fourier transform of the function \( f(t) \) is that \( f(t) \) satisfies the Dirichlet condition or is absolutely integrable within the interval \((-\infty, +\infty)\), that is, \( \int_{-\infty}^{\infty} |f(t)| dt \) must be a finite value.

The spread spectrum communication system refers to the spectrum of the information signal to be transmitted is extended into a wide band signal by a specific spreading function (independent of the information signal \( f(t) \) to be transmitted) and transmitted into the channel; and then the extension of the spectrum is compressed by using the corresponding technique or means on the receiving end, to restore the original information to be transmitted information signal bandwidth, and thus reach the purpose of transmission of information communication system. That is to say, the radio frequency bandwidth required to transmit the same information signal far exceeds the minimum bandwidth necessary for transmitting the information signal. Information is no longer an important factor in
determining the bandwidth of the RF signal. The bandwidth of the RF signal is mainly determined by the spread spectrum function.

In this experiment, the purpose of spread spectrum is to widen the spectrum of the transmitted signal before transmitting the information, so that it can obtain stronger anti-interference ability and high transmission rate, and because the same frequency band different patterns can carry information from different users, so spread spectrum also increases the reuse rate of the band. In this experiment, the stream 0 is expanded to 0101, and 1 is expanded to 1010.

2.5. Scrambling algorithm

In order to ensure the security of information, it is necessary to scramble the unencrypted information before modulating it. The common iterations are scrambled and the scrambled images have regular fringes, which are easy to be deciphered. Therefore, this paper uses a pseudo-random code chaotic scrambling method. The scrambling image obtained by this method has the advantages of high scrambling degree and good confidentiality, and can be encrypted and decrypted according to the parameter if the corresponding pseudo-random parameter value is set. The chaotic phenomenon is a deterministic, stochastic process that occurs in a nonlinear dynamical system. This process is neither periodic nor convergent, it is extremely sensitive to the initial value, and the long-term orbital behavior is unpredictable, the resulting sequence is called scrambling set by Li-York. The chaotic sequence scrambling algorithm of Logistic is adopted in this paper, and the mapping formula is [11, 12]:

$$x_{k+1} = \mu x_k (1 - x_k)$$

Where $0<\mu \leq 4$ is the branch parameter, $x_k \in (0, 1)$. The research work of chaotic dynamical systems indicates that when $3.5699457<\mu \leq 4$, the Logistic map operates in chaotic states. In other words, the sequence \{ $x_k : k =0, 1, 2, 3 …$ \} generated by the initial condition $x_0$ under the action of the Logistic map is aperiodic, non-convergent and very sensitive to the initial value. The scrambling image obtained by this method has the advantages of high scrambling degree and good confidentiality, and can be encrypted and decrypted according to the parameter if the corresponding pseudo-random parameter value is set [13]. Figure 5 is a schematic diagram of the image before and after the modulated information is scrambled in this experiment. (a) An image that is scrambled before, (b) is a scrambled image:

![Figure 5](image.png)

Figure 5. Modulation information before and after scrambling.

As the amount of information embedded in this experiment is relatively small, the length of the spread spectrum discontent 128 digits part with 0 completion, making the image arrangement is very regular. But through Logistic chaotic sequence scrambling algorithm, completely disrupted the previous arrangement, the security margin has been improved.

3. Information Modulation

The information to be modulated in this experiment is a string of Baidu URLs, which is character information, but the modulation to the plaintext image is a string of 0/1 stream, so the string needs to be changed to 0/1 stream through certain rules. In this paper, the coding rule of the two-dimensional code is chosen to change the character information into 0/1 stream. Two-dimensional code character encoding table shown in Table 1:
Table 1. Two-dimensional code character encoding table.

| Char | Value |
|------|-------|
| 0    | 0     |
| 1    | 1     |
| 2    | 2     |
| 3    | 3     |
| 4    | 4     |
| 5    | 5     |
| 6    | 6     |
| 7    | 7     |
| 8    | 8     |
| 9    | 9     |
| A    | 10    |
| B    | 11    |
| C    | 12    |
| D    | 13    |
| E    | 14    |
| F    | 15    |
| G    | 16    |
| H    | 17    |
| I    | 18    |
| J    | 19    |
| K    | 20    |
| L    | 21    |
| M    | 22    |
| N    | 23    |
| O    | 24    |
| P    | 25    |
| Q    | 26    |
| R    | 27    |
| S    | 28    |
| T    | 29    |
| U    | 30    |
| V    | 31    |
| W    | 32    |
| X    | 33    |
| Y    | 34    |
| Z    | 35    |
| SP   | 36    |
| $    | 37    |
| /    | 43    |
| %    | 38    |
| +    | 40    |
| -    | 41    |

Through the two-dimensional code encoding rules Baidu Web site convert into a string of code stream, and then spread spectrum processing for this string of code streams. Since the mesh needs to be embedded in the same size as the original image, the array after the spread spectrum is placed in the same array as the original size, and the lack of part is filled zeros. At this point, a matrix of 0/1 equal to the original size is obtained, and then the matrix is scrambled, through a certain rule can be divided into different status classification, respectively, 00,01,10,11, by judging different status calls a different template for screening.

When the processed information is modulated, a screen template based on the phase characteristics of the space filling curves is selected. The space filling curve is used to fill the black regions of the map with a determined trajectory in the printing process, forming a modulation dot with different area rates. The filling route is shown in (b) above in Figure 2. According to this, we can get a 4 * 4 base template, through the basic template 90 ° , 180 ° , 270 ° rotation to get four different templates, according to the different forms of modulation information call different templates.

4. Screening Result

The test chart selected in this experiment is 128 * 128 color logo map, the modulated dark message is www.baidu.com, through the two-dimensional code encoding rules to convert the string to 0/1 code stream, the spread spectrum of its 0 to [0 1 0 1], 1 expanded to [1 0 1 0], the plaintext information is complemented by the tail zeros padding to 128 * 128 of the 0/1 matrix, and then the matrix is transformed into irregularly arranged matrix for information modulation. By dividing the bits in the matrix into groups with two bits in each group, and then call different templates according to different morphologies, the screening contrast diagram is shown in Figure 6, (a) the ordinary amplitude modulation screening, (b) the ordinary frequency modulation screening, (c) the space filling curves phase feature screening, (d) dots shape of space filling curves phase feature screening:

![Image of screening results](image-url)

(a) AM screening  (b) FM screening  (c) space filling curves phase feature screening  
(d) dots shape of space filling curves phase feature screening

Figure 6. Screening effect comparison.
Comparing the figures, the results of the screening based on the phase feature of the space filling curve is more delicate, the reduction degree of original image is high and the reproduction effect of image is clear. In the amplitude modulation screening, we always directly can see the presence of moire, even more serious in the case of zooming. What’s more, it has a great bad influence on the processing to the edge in the middle of the logo part for the image, causing a clearly fuzzy. In the FM screening, effectively solved the problem of moire, but lost the details of the image edge. The same time, the recovery for the edge in the middle of the logo part of the image is low and the original picture reproduction is not good. The method that screening based on the phase feature of the space filling curves is proposed, saving the problems. And retain more details of the original image avoiding moire, the edge details are more delicately and smoothly handled making a better visual and significantly improving image reproduction effect. Make the security of encrypted information better by enlarging the dots which are 'back' type irregular distribution.

5. Conclusion
In view of the existence of the moire and image reproduction ineffective problem, this paper applies the idea of space filling curves to half tone image screening and information hiding, which can solve the above problems effectively. Experimental results show that the image after the screening can not only solve the problem of moire, but also a better reproduction of the original map, the algorithm of this paper has a broad development prospect in the field of security printing.

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7. References
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