Journal of Information Hiding and Multimedia Signal Processing ©2018 ISSN 2073-4212
Ubiquitous International Volume **9**, Number **1**, January **2018**

High Capacity Reversible Data Hiding Algorithm for Color Image Based on Bicubic Interpolation Extension

Qiu-Yu Zhang, Qi-Yan Dou, Yan Yan, Wen-Jin Hu

School of Computer and Communication
Lanzhou University of Technology
Gansu, Lanzhou, 730050, P. R. China

zhangqylz@163.com; 1147025638@qq.com; yanyan@lut.cn; 295105067@qq.com

Received February, 2017; revised October, 2017

Abstract. *In order to solve the problems that the existing algorithms, especially interpolation expansion algorithms, which is hardly applicable to the color image and of low embedding capacity, cannot alleviate contradictory between the amount of embedding capacity and the perceptual quality of image, a novel high capacity reversible data hiding (RDH) algorithm for color image based on bicubic interpolation expansion was proposed in this paper. The proposed algorithm makes full use of the correlation among RGB color components and the interpolation room redundancy to embed the secret data in the form of one dimensional sequence. The four low bits of each color component, the edge interpolation pixel and the reference pixel can be selected as the embedding position. The adjacent 16 pixel values are used to predict the value of the interpolated pixel. Experimental results show that the maximum embedding capacity of the proposed algorithm could reach to 6.732 bpp, and the image quality was very good when the hiding capacity was large. At the same time, the proposed algorithm eliminated the location map, could adaptively select the hiding capacity, and solved the problem that the interpolation expansion algorithm cannot be directly used in color image.*
Keywords: Reversible data hiding (RDH), Color image, Bicubic interpolation extension, Image perception of quality, High capacity.

---

1. **Introduction.** With the rapid development of computer network technology and transmission of more and more image information in the public network, it is difficult to guarantee the authenticity and integrity of multimedia data. The emergence of data hiding technology has greatly protected the security of multimedia information [1]. Compared with the technology of data hiding, the RDH technology can not only hide the secret message in the cover image, but also restore the original cover image, thus the safety protection of multimedia information is realized. The data hiding technologies are playing a pivotal role in the fields such as satellite and military images, medical images, two-dimensional engineering drawings, cloud environment, the application of privacy protection and other [2]. In the practical application, the application requirement of color image is larger than that of gray level, so it is of great significance to study RDH technology of color image [3].

Nowadays, all kinds of RDH algorithms are proposed by scholars, which mainly include three kinds of methods difference expansion, histogram shifting and lossless compression

[4, 5]. Xiong et al. [6] proposed a RDH using prediction error difference expansion without location map. In his method, the binary auxiliary location map method is used to embed and extract secret data, which did not cancel the mapping in a real sense, so its embedding capacity is not large. On the basis, Zhu et al. [7] proposed a RDH algorithm for prediction error difference expansion by reducing the location map. The embedding capacity is increased by reducing the location map, but when the embedding capacity equals to that in [6], the perceptual quality of the cover image will be poor. Lee et al. [8] introduced an adjustable and RDH method based on multiple-base notational system without location map, which can increase the capacity of the secret data further. But there is no secret data being embedded in reference pixel of the first row and the first column, so the embedding capacity is still not good enough. Li et al. [9] proposed a RDH algorithm of pixel-value-ordering and prediction-error expansion, the pixel-value-ordering is incorporated into the technique of predicting the error expansion, the maximum and minimum values of each block are predicted by the size of the other pixel value, and the embedding process is realized by the prediction-error expansion. The algorithm reduces the number of pixel shift, reduces the degradation of image quality, and chooses to embed secret data in the smooth region, but the embedding capacity is limited. Li et al. [10] proposed the RDH scheme for color image based on prediction-error expansion and cross-channel correlation, the prediction accuracy of this algorithm is higher, so its embedding capacity and perceptual quality are better than those in [9]. Ou et al. [11] proposed a RDH method for color image based on channel-dependent payload partition and adaptive embedding, which selects the low energy region to embed secret message, the change of pixel is reduced, so the perceptual quality is improved. A RDH method is proposed by Liu et al. [12], which combines the adaptive prediction technique with the histogram shifting. The proposed method represents two prediction methods. One is predicting the edge pixels, and the other is to predicting the remaining pixels. The embedding capacity is controlled by setting the threshold value, and when the threshold value is about 8, the embedding capacity reaches the maximum value. Based on the sorting of the histogram shifting method to embed secret data, a better perceptual quality can be obtained. But compared with the method in [9], the proposed algorithm has the same disadvantage, the low embedding capacity. An adaptive RDH algorithm based on the difference histogram and Pyramid structure is proposed by Lu et al. [13], which simply analysis the advantages and disadvantages of difference expansion and histogram shifting. This algorithm embedded secret data with three layers of conical structure similar to pyramid. That is to say, the algorithm embedded secret data three times, with the most in the first layer, and the least in the third layer. The peak signal to noise ratio (PSNR) is more than 30 dB when the embedding capacity is 1.0 bpp. Fu et al. [14] proposed a RDH method based on difference histogram shifting and exploiting modification direction (EMD), which uses the adjacent pixels and edge matching to predict the difference histogram, histogram shifting method to embed secret data, and compression mapping to solve the problem of overflow and underflow. At the same time, in order to get a higher embedding capacity, the nonary EMD algorithm and multi-layer embedding mechanism are introduced. However, with the increasing of embedded layer, the perceptual quality also decreases significantly. Pan et al. [15] proposed a RDH based on local histogram shifting with multilayer embedding. The peak value of the histogram is kept as the reference pixel, and the secret data is embedded by the adjacent pixel value. Without using key information of the peak point, the peak can be found directly from the histogram to extract the secret data through the peak. Using the multi-layer embedding process, the embedding capacity of this algorithm is very good, but the histogram changes obviously. Compared with methods in [13, 14], the drawback is that the perceptual quality of stego-image has declined significantly.

Interpolation expansion [16, 17] is also a commonly used RDH technology in recent years. This technology can be used to expand the original image to empty a lot of redundant rooms to hide the secret data, which has a good effect on increasing the embedding capacity and improving the perceptual quality. The existing data hiding interpolation algorithm mainly includes the adjacent interpolation, linear interpolation and parabolic interpolation [18]. Wang et al. [19] proposed a RDH for high quality images exploiting interpolation and direction order mechanism. The mechanism divides pixels into two categories: wall pixels and non-wall pixels. The interpolation error is used to embed the secret data over the interpolation prediction method for wall pixels, and for non-wall pixels secret data are embedded by using the histogram shift. Moreover, the performance of the proposed scheme is more stable for different images. At the same time the embedding capacity and perceptual quality effects are also very good compared to the prediction difference expansion and histogram shifting methods above. By improving the RDH algorithm based on histogram shifting and interpolation extension proposed by Hong and Chen's method [16], a high capacity RDH algorithm based on interpolation, difference expansion and histogram shifting is proposed by Lu et al. [20]. In this method, the embedding capacity is increased by embedding secret data into the reference pixels. However, there is no interpolation expansion embedding in the first column of the reference pixel or the first line, so the embedding capacity needs to be improved, and the PSNR value does not increase, even lower than the Hong and Chen's method. Afterwards, Govind et al. [21] proposed an improved directional interpolation algorithm of RDH algorithm by improving the method of Lu in [20]. The pixel prediction error can be reduced more accurately by using the directional interpolation prediction algorithm. The pixel value is closer to the original pixel, and more embedded pixels can be found, so the perceptual quality and the embedding capacity are better than the algorithm of Lu in [20]. Vigila et al. [22] proposed a secret data hiding method in spatial domain image using adjacent interpolation. In this method, the number of embedded secret data is determined by the logarithm of the distance between adjacent pixels, so the algorithm has low computational complexity. The disadvantage is that no secret data is embedded in the reference pixel, and the secret data is just embedded in the adjacent three pixels, so the embedded capacity is low. But when the embedding capacity is low, the perceptual quality is very good. Ajeeshvali et al. [23] proposed a steganography based on integer wavelet transform and bicubic interpolation. The low frequency sub-band is not used to embed secret data, and the perceptual quality and embedded capacity are not very good. Above the interpolation algorithms are also only applicable to gray image, cannot be directly used in color image. There are color space conversion methods besides separating the R-G-B channels of Ou et al. [11] to handle color image data hiding. However, the application of color space conversion is relatively less in reversible data hiding, most of them are used in watermarking and steganography. For instance, Al-Gindy et al. [24] transformed the RGB into YCbCr color space, and selected the Y channel of its DCT's low frequency to embed data. In his method, the perceptual quality is better, but the embedding capacity is up to 1.0 bpp. Santhi et al. [25] proposed a method of HSV color space conversion of steganography, his algorithm used the face image as the cover image, to separate the skin and non-skin regions, and skin tone detection is performed using HSV color space. Data is embedded into some regions of the skin and not to the whole region, so the embedding capacity is relatively small, but the perceived quality is very good.

In an effort to tackle these disadvantages, we present a RDH algorithm for color images, which can eliminate the location map and adaptively select the embedding capacity by improving the traditional bicubic interpolation algorithm. The bicubic interpolation algorithm is an improved algorithm, which is based on the neighboring pixel prediction method to predict the value of the first two rows and the first two columns. While increasing the embedding capacity, it also reduces the complexity of the traditional bicubic interpolation expansion algorithm. The bicubic interpolation formula is used to predict the interpolated pixel values of the rest, and the predicted pixel values are more accurate. Since the color component of original cover image is represented by 8 bits, and the important information is the top 4 bits, so the low four bits for each color component are used to embed secret data, which can ensure that the important data of the original cover image is unchanged. Experimental results show that the proposed algorithm is very suitable for high capacity data embedding, and ensure the balance point between the embedded capacity and perceptual quality. When the interpolation expansion magnification $k = 3$, the embedding capacity reaches 6.732 bpp, and the PSNR value is above 36 dB.

The rest of paper is organized as follows. Section 2 describes the main idea of high Capacity RDH Algorithm for Color Image. Section 3 describes the implementation of the proposed algorithm, and the detailed data hiding procedure, extracting and restoring procedure are then given. Section 4 gives the experimental results and the corresponding analysis. Finally, we conclude our paper in Section 5.

2. The Main Idea of High Capacity RDH Algorithm for Color Image.

2.1. The Improved Bicubic Interpolation Expansion Algorithm.

On the basis of the characteristic of the pixel value obtained by the cubic interpolation, the bicubic interpolation algorithm is improved as follows: the pixel value of the first two rows and the first two columns of the matrix, which are not directly calculated by using the bicubic interpolation algorithm, but using the correlation between adjacent pixels to predict the pixel value. The predicted pixel values are very close to the results of the bicubic interpolation algorithm, which not only reach the effect, but also save the time. For the remaining interpolation pixels, the pixel value is obtained by using the bicubic interpolation algorithm, which greatly reduces the complexity of the bicubic interpolation algorithm, and achieves the accurate prediction of the pixel value simultaneously.

The bicubic interpolation is also called cubic convolution interpolation. It is a more complex interpolation method, which can create a smoother image edge than the bilinear interpolation. The algorithm makes use of the 16 points around the sampling point to make a cubic interpolation, which considers not only the influence of 4 gray directly adjacent points, but also the influence of the rate of change of the pixel value of each adjacent. So the value of pixels obtained by this algorithm is more close to the original pixel value. The cubic operation can get more close to the high resolution image of the amplification effect, but it will lead to a dramatic increase in the amount of computation. This algorithm needs to select the interpolation basis function to fit the data. The bicubic interpolation formula is as follows:

$$f(i+u, j+v) = [\mathbf{A}] * [\mathbf{B}] * [\mathbf{C}] \tag{1}$$

where **A**, **B** and **C** are the matrix, and their forms are as follows:

$$[\mathbf{A}] = [S(1+u) \quad S(u) \quad S(1-u) \quad S(2-u)] \tag{2}$$

$$\mathbf{B} = \begin{bmatrix} f(i-1,j-2) & f(i,j-2) & f(i+1,j-2) & f(i+2,j-2) \\ f(i-1,j-1) & f(i,j-1) & f(i+1,j-1) & f(i+2,j-1) \\ f(i-1,j) & f(i,j) & f(i+1,j) & f(i+2,j) \\ f(i-1,j+1) & f(i,j+1) & f(i+1,j+1) & f(i+2,j+1) \end{bmatrix} \tag{3}$$

$$[\mathbf{C}] = [S(1+v) \quad S(v) \quad S(1-v) \quad S(2-v)]^T \tag{4}$$

where $f(i,j)$ represents the gray value of the pixel point (i,j), u and v are the values of i, j and k operations respectively, and $u = rem(i,k)/k$, $v = rem(j,k)/k$. u and v are the floating point number of interval [0,1).

Interpolation function $S(w)$ is the approximation of $sin(w \times \pi)/w\pi$, w is a random variable between [-2, 2]. The expressions for interpolating basis functions defined by

$$S(w) = \begin{cases} 1 - 2|w|^2 + |w|^3 & |w| < 1 \\ 4 - 8|w| + 5|w|^2 + |w|^3 & 1 \le |w| < 2 \\ 0 & |w| \ge 2 \end{cases} \quad (5)$$

The interpolation function is shown in Fig. 1.

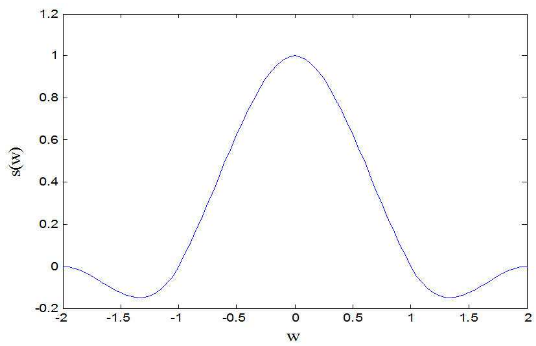


FIGURE 1. The basis function of bicubic interpolation.

Implementation steps of improved bicubic interpolation algorithm are as follows:
Step 1.: Set the interpolation expansion magnification k=3.

TABLE 1. The running time of different k

Interpolation expansion magnification	k=1	k=2	k=3
Running time(s)	15.542	65.460	154.117

It can be seen from Table 1 that the running time is 154.117 s, when $k = 3$, it presents a trend of exponential growth. In other words, the computational time complexity has been very high, we can assume that when the k value is four, the running time will be longer, and this conjecture is verified by experiments, which is not what we want.

TABLE 2. The PSNR of different Capacity (bpp) and k

Capacity (bpp)	Image	0.257	0.715	1.030	1.402	2.317	3.000
k=1	Airplane	41.299	37.045	–	–	–	–
	Baboon	41.537	37.131	–	–	–	–
k=2	Airplane	47.185	42.625	41.191	39.807	37.521	–
	Baboon	47.529	43.079	41.468	40.073	37.669	–
k=3	Airplane	50.325	46.219	44.528	42.998	40.846	39.897
	Baboon	51.108	46.536	44.942	43.480	41.129	40.145

It can be seen from Table 2 that the maximum embedding capacity can reach 0.715 bpp, when k=1, and the corresponding PSNR value has been relatively low. Similarly, the maximum embedding capacity is 2.317 bpp when k=2, it seems a lot better than the k=1, but this is not the highest embedding capacity we want to achieve. And the embedding capacity can reach 3.0 bpp when k=3, Table 2 lists only the case when the embedding capacity is up to 3. Combined with Table 1, the running time is also acceptable when

k=3, and the PSNR value is also relatively ideal. Therefore, we choose k=3 as the most suitable interpolation multiple.

Step 2.: Insert two rows into the $m \times n$ matrix of the image between every two rows, and insert two columns between every two columns, to get a $3m \times 3n$ matrix. The pixel is the original pixel, whose row and column coordinates are the multiple of 3, and the remaining pixels are interpolation pixels.

Supposed the original image matrix is $\mathbf{A}_1 = \begin{bmatrix} 226 & 223 \\ 226 & 223 \end{bmatrix}$, and the matrix after interpolation expansion is $\mathbf{A}_2 = \begin{bmatrix} \times & \times & \times & \times & \times & \times \\ \times & \times & \times & \times & \times & \times \\ \times & \times & 226 & \times & \times & 223 \\ \times & \times & \times & \times & \times & \times \\ \times & \times & \times & \times & \times & \times \\ \times & \times & 226 & \times & \times & 223 \end{bmatrix}$. Where '×' is the value of interpolated pixel.

Step 3.: Calculate the value of interpolated pixel. Firstly, the first two rows and two columns pixel values of $\mathbf{A}_2$ are calculated by the adjacent pixel value prediction method is as follows

$$\mathbf{A}_2(i,j) = \begin{cases} \mathbf{A}_1(1,1) & i \le 3, j \le 3 \\ \mathbf{A}_1(2,1) & i = 6, j \le 2 \\ \mathbf{A}_1(1,2) & i < 3, j = 6 \\ (\mathbf{A}_1(1,1) + \mathbf{A}_1(2,1))/2 & 3 < i < 6, j \le 2 \\ (\mathbf{A}_1(1,1) + \mathbf{A}_1(1,2))/2 & i < 3, 3 < j < 6 \end{cases} \tag{6}$$

Next, calculate the value of the remaining interpolation pixels by Eq.(1)–Eq.(5). These pixel values are obtain by three operations from the neighboring 16 pixel values. The results are very accurate, which is very close to the value of the original pixel in $\mathbf{A}_1$.

2.2. **The Adaptive Embedding Principle.** The adaptive embedding mainly includes the adaptability of the embedding capacity and embedding position. In this paper, the proposed algorithm can flexibly apply interpolation expansion multiple k to realize the adaptive of embedding capacity. When k=1, the interpolation expansion is not applied to make space, it directly embeds the secret data by using original image. So it is suitable for the RDH with low embedding capacity. When k=2, the original cover image is enlarged by 2 times, in other words, a row is inserted between the two rows, and a column is inserted between each of the two columns of the original cover image. So there will be a larger space to hide secret data. As a result, the RDH is obtained, which is suitable for moderate embedding capacity. When k=3, the original cover image is enlarged by 3 times, that is to say, two rows are inserted between the two rows, and two columns are inserted between each of the two columns of the original cover image. Thus the space for hiding secret data will be larger. The RDH is obtained, which is suitable for high embedding capacity. Therefore, the user can realize the adaptive selection of the required capacity of the embedded secret data only by changing the interpolation expansion multiple k.

2.3. **Location Map Eliminating Method.** Location map is one of the most effective ways to extract the secret data, which is used to determine the embedding position of the secret data for the receiver. But the location map occupies a certain space, so the embedding capacity decreases. In this method, cover image and secret data both are transformed into one dimension by the whole process. The extraction side only needs to know the embedding method of the first pixel, and the other pixels use the same method. All of these are agreed in advance, so there is no need of other additional information.

Therefore, in the whole process, it is not necessary to use the location map to determine the location of the embedded secret data, which can directly embed and extract the secret data, and a high capacity is obtained at the same time.

2.4. **Overflow Phenomenon Eliminating Method.** For the pixel matrix after interpolating, it has no original pixel for the first two rows and two columns, whose pixel values are obtained by the average value of the adjacent one or two pixels after interpolating, as shown in Eq.(6). Therefore, the first two rows and two columns of pixels do not appear the overflow or underflow phenomenon after interpolating. And in the embedding process, the XOR operation is done, the pixel value also in the range of [0, 255], so the pixel value overflow does not occur.

Similarly, the other pixels of interpolation are calculation by bicubic interpolation formula. The pixel value of the interpolation point is obtained by the nearest sixteen reference points in the rectangular grid, and there is no appearance of pixel overflow too. So, phenomenon that the pixel value is less than 0 or more than 255 will not appear in the whole calculation process.

3. **The Proposed Algorithm.** According to the idea of Section 2, the embedding and extracting process of the proposed algorithm is simple and easy to implement. According to the prescribed position, the secret data can be embedded and extracted directly without the location map, and overflow or underflow phenomenon will not occur in the embedding process of improved bicubic interpolation expansion. In addition, there is no need of other additional information with the extracting of the secret data. The principle diagram of RDH algorithm for color image is shown in Fig. 2.

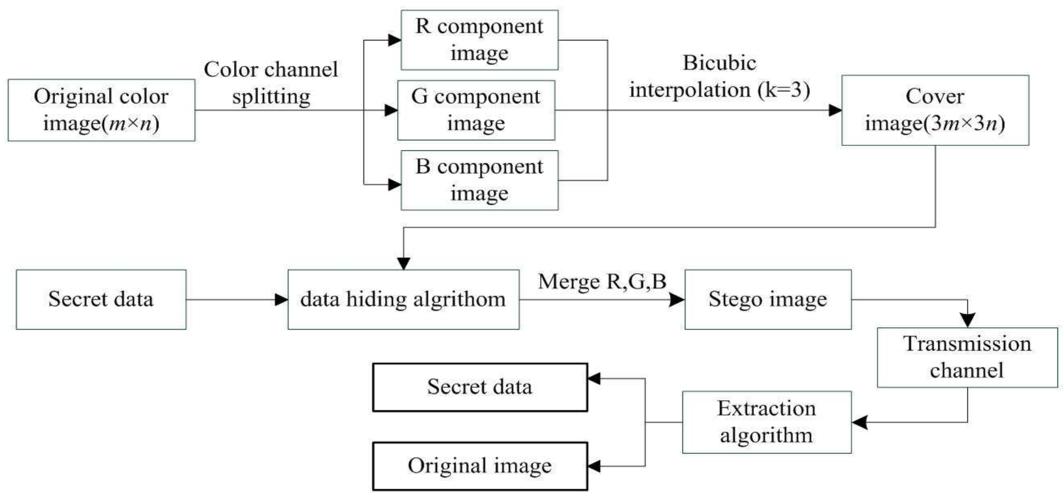


Figure 2. The principle diagram of high capacity RDH algorithm for color image.

3.1. **Data Hiding Procedure.** $CI(m \times n)$ is the original color cover image in the embedded processing, and $SI(mm \times nn)$ is stego image, where, $mm = 3m$, $nn = 3n$. ff is called red component cover image. r and r' represent one dimensional red component cover and stego image respectively. f is the final interpolation image, and s represents one dimensional secret data. $\mathbf{CR}, \mathbf{CG}, \mathbf{CB}$ represent the matrix representation of three-color components IR, IG, IB in the original cover image.

Step 1.: Three-color components named IR (red), IG (green) and IB (blue), are separated from the original color cover image, and the pixels of each color component are represented by one byte.

Step 2.: ff is treated as the IR image. Firstly, the k=3 interpolation expansions for matrix $\mathbf{CR}$ of ff is achieved, and the matrix $\mathbf{CR}_1$ after interpolating is obtained. The pixel value of each matrix interpolation point is calculated.

The specific calculation process is as follows:

1) Calculating the value of the edge interpolation pixel and using adjacent pixel value to predict, which is similar to type Eq.(6), $f(1, j)$, $f(2, j)$, $f(i, 1)$, $f(i, 2)$ are obtained. This is the innovation point of this paper on the bicubic interpolation. This can greatly reduce the complexity of the bicubic interpolation algorithm, and the calculated pixel value is close to the value of the cubic interpolation calculation. The bicubic interpolation expansion calculation has a very high accuracy of the pixel value. Therefore, this method has a high accuracy of the predicted pixel value.

2) Calculate the value $f(i, j)(mm > i > 2, nn > j > 2)$ of the remaining interpolated pixels. The calculation process is very complex, and the corresponding pixel value is predicted, which is based on the neighboring 16 pixel values. Firstly, calculate the matrix $\mathbf{A}, \mathbf{B}, \mathbf{C}$ according to $S(w)$ and u, v. Then, three matrices are calculated to obtain an interpolated pixel value, and the other interpolated pixel value is calculated too in accordance with this process. The whole process uses a lot of auxiliary variables and matrix transformations. The following process shows how to calculate the matrix $\mathbf{A}, \mathbf{B}, \mathbf{C}$.

(a) Firstly, the value of matrix $\mathbf{a}, \mathbf{b}, \mathbf{c}, \mathbf{d}$ is obtained, the detail calculation as follows: $a = ff(1, :)$; $c = ff(m, :)$; $b = [ff(1, 1), ff(1, 1), ff(:, 1)', ff(m, 1), ff(m, 1)]$; $d = [ff(1, n), ff(1, n), ff(:, n)', ff(m, n), ff(m, n)]$. Where $\mathbf{a}, \mathbf{b}, \mathbf{c}, \mathbf{d}$ are the intermediate variables to get the final pixel value.

(b) $a_1 = [a; a; ff; c; c]$; $b_1 = [b; b; a_1'; d; d]$; $fff = b_1'$, then the final result $f = double(fff)$ is obtained, where, a_1, b_1, fff are the intermediate variables to get the final pixel value. $\mathbf{a}_1'$, $\mathbf{b}_1'$ are the transpose matrix of $\mathbf{a}_1$, $\mathbf{b}_1$.

(c) Using the improved bicubic interpolation expansion to substitute the value of the above step f into Eq. (3), then calculate the matrix $\mathbf{A}$, $\mathbf{B}$, $\mathbf{C}$ according to Eq.(2)–Eq.(5). Finally, the pixel value $f(i, j)$ of one of the interpolation point is calculated by Eq.(1), then calculate $\lfloor f(i, j) \rfloor$, where, $\lfloor \cdot \rfloor$ represents rounding down.

(d) According to the above Step (c), the pixel values of the other interpolation points are calculated respectively, and the interpolation matrix $\mathbf{CR}_1$ is obtained.

Step 3.: A pixel bit of matrix $\mathbf{CR}_1$ is composed of 8 bits. In general, the top 4 bits contain important information of the cover image, so the cover's 4 low bits are used to embed secret data. The embedding process is as follows:

1) $\mathbf{CR}_1$ is transformed into one dimensional vector $\mathbf{r}$. The four low bit string of each pixel r_1 is extracted. All of the low four bits of the rest top four bits are supplemented by '0000', and r_2 is obtained. Moreover, the secret data is transformed into one dimensional vector $\mathbf{s}$, the bit string s' is obtained.

2) Every four bits of s' is done a simple XOR operation with r_1 in order, $h = r_1 \oplus s'$ is obtained, where h represents the bit string after embedding secret data.

3) h is separated by every four bits. Replace the low four bits in h with the r_2, and r' is obtained. The r' is stego image IR$'$ after transforming into the matrix.

Step 4.: The same operations as Step 2 and Step 3 are finished for matrix $\mathbf{CG}$ of IG, matrix $\mathbf{CB}$ of IB. The stego image IG$'$, IB$'$ are obtained. The final stego image SI is obtained, which is combined by three-color components.

3.2. **Extracting and Restoring Procedure.** The extraction of secret data and the recovery of the original cover image are simple, which is the inverse process of embedding (where, IR$'$, IG$'$, IB$'$ represents color component images of the stego image).

Step 1.: Three-color components of the stego image SI is divided in to IR$'$, IG$'$, IB$'$.

Step 2.: IR$'$ is transformed into one dimensional vector. After embedding secret data, the bit string r' is obtained. In addition, h is obtained by separating r' every four bits, and the secret data s' is calculated by equation $h = r_1 \oplus s'$.

Step 3.: The same operation as Step 2 get IG$'$ and IB$'$. The bit string s' is transformed into matrix. Finally, the secret data s is got.

Step 4.: Three-color components of interpolation expansion are obtained after extracting secret data.

Step 5.: Remove the first two rows and two columns of the three-color component matrix, then the $mm/3$, $nn/3$ operations (deleting two rows in the middle of each four rows and deleting two columns in the middle of each four columns). Three-color components are obtained, which has the same size with the original image. Then combine the three-color components. Finally, the original cover image CI with the size $m \times n$ is obtained.

4. **Experimental Results and Analysis.** In the selection of experimental materials, the six 24 bits color images Lena (512×512), Baboon (512×512), Airplane (512×512), Peppers (512×512), Boat (512×512), Barbara (720×576) from the standard color gallery are chosen as cover test image, and the random color images is selected as secret data. Experimental hardware platform is Inter Core i3CPU, 350M, 4G, 2.27GHz. The experimental environment is MATLAB R2012a under Win 7.

After many experiments, the proposed algorithm makes a detailed experiment and analysis on the embedding capacity and image quality of different cover images. The advantages of the proposed algorithm are proved by comparing with the popular algorithms and the similar algorithms in recent years.

4.1. **Performance Evaluation Standard.** In this paper, the performance evaluation standard is measured by the embedding bit rate (bits/pixels, bpp) and the peak signal to noise ratio (PSNR). Where, the *bpp* is an index to evaluate the size of embedded capacity, the greater the value of *bpp* is, the greater the capacity is. Where, $m \times n$ is the size of the original cover image. The definition of *bpp* is shown as follows

$$bpp = \frac{Hidden \quad data \quad bits}{m \times n} \tag{7}$$

The $PSNR$ is used to make an objective evaluation of image quality, the greater the value of $PSNR$ is, the greater the image quality is. In the color graphics, considering that the color image is represented by the combination of RGB three primary colors, each color component is represented by one byte. The expression of $PSNR$ is as follows:

$$PSNR = 10log_{10}[\frac{MAXPIX}{(MSE(IR) + MSE(IG) + MSE(IB))/3}] \tag{8}$$

where, $MAXPIX$ is the maximum value 255^2, MSE is the mean square error between the cover image CI and stego image SI, its definition as follows:

$$MSE = \frac{1}{m \times n} \times \sum_{i=1}^{m} \sum_{j=1}^{n} (CI(i,j) - SI(i,j))^2 \tag{9}$$

The structural similarity (SSIM) is also a kind evaluation index of image quality. $SSIM$ measures image similarity from three aspects of brightness, contrast and structure respectively. X represents the cover image CI, Y represents the stego image SI.

$$SSIM(X,Y) = l(X,Y) \times c(X,Y) \times s(X,Y) \tag{10}$$

The range of $SSIM$ is [0, 1], the greater of the value, the smaller of the image distortion.

$$l(X,Y)=\frac{2\mu_X\mu_Y+C_1}{\mu_X^2+\mu_Y^2+C_1}\quad c(X,Y)=\frac{2\sigma_X\sigma_Y+C_2}{\sigma_X^2+\sigma_Y^2+C_2}\quad s(X,Y)=\frac{\sigma_{XY}+C_3}{\sigma_X\sigma_Y+C_3}$$

where, C_1, C_2 and C_3 are constants, To avoid the denominator equal to 0, usually take $C_1=(K_1\times L)^2$, $C_2=(K_2\times L)^2$, $C_3=C_2/2$. Generally, K_1=0.01, K_2=0.03, L=255. μ_X and μ_Y represent the mean values of images X and Y, respectively. σ_X and σ_Y represent the variance of the images X and Y, respectively. σ_{XY} represents the covariance of the image X and Y, namely:

$$\mu_X=\frac{1}{m\times n}\times\sum_{i=1}^{m}\sum_{j=1}^{n}X(i,j)\quad \sigma_X^2=\frac{1}{m\times n-1}\times\sum_{i=1}^{m}\sum_{j=1}^{n}(X(i,j)-\mu_X)^2$$

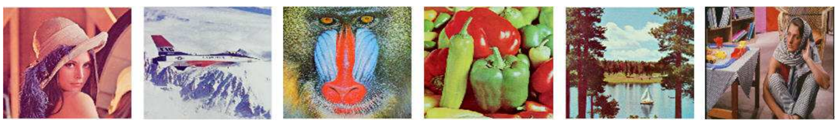
$$\sigma_{XY}=\frac{1}{m\times n-1}\times\sum_{i=1}^{m}\sum_{j=1}^{n}(X(i,j)-\mu_X)(Y(i,j)-\mu_Y)$$

In practical application, images can be divided by sliding window, the total number of the block is N, considering the impact of the window shape to the block, use the Gauss weighted to calculate the mean, variance and covariance of each window, and then calculating the structural similarity (SSIM) of corresponding block, the mean value as the structure similarity measure of two images, namely mean structural similarity (MSSIM):

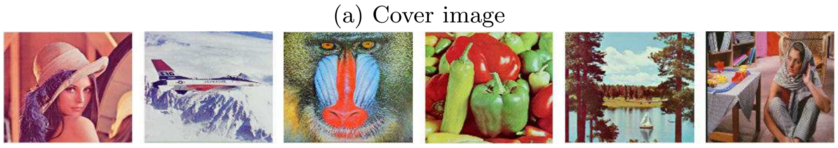
$$MSSIM(X,Y)=\frac{1}{N}\sum_{k=1}^{N}SSIM(X_k,Y_k)\tag{11}$$

4.2. **Performance Analysis of the Algorithm.** Set k=3 in the experimental procedure. Different covers are embedded with different capacity or the same capacity of secret data respectively in order to verify the change of image quality. The experimental results show that the proposed algorithm has a higher embedding capacity, the perceptual quality is better, and the performance is more stable when the embedding capacity is higher.

In Fig. 3(a), six different color images lena.bmp, Airplane.jpg, Baboon.jpg, Peppers.tiff, Boat.tiff and Barbara.bmp are selected as the original cover image. Fig. 3(b) is the stego images correspondingly.



(a) Cover image



(b) Stego image

FIGURE 3. The cover images before and after RDH.

In the experiment, the secret data of the smaller capacity and the maximum capacity are embedded in each cover image respectively. The variation of $PSNR$ and $MSSIM$ value, the average PSNR (AVR $PSNR$) and the average MSSIM (AVR $MSSIM$) with the different cover images as shown in Table 3.

As can be seen from Table 3, with the increase of the embedding capacity, the corresponding perceptual quality is reduced gradually. This shows that the proposed algorithm can get a better perceptual quality of the smooth image, also a better perceptual quality

TABLE 3. The $PSNR$ of different embedding capacity

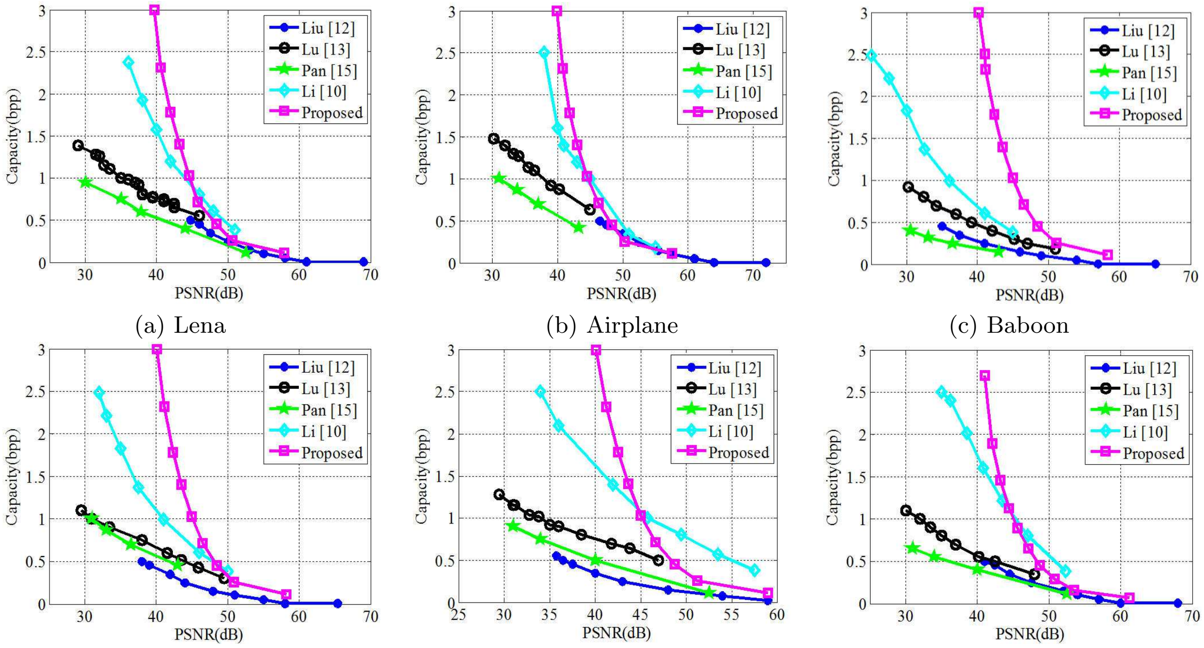
Performance	Lena	Airplane	Baboon	Peppers	Boat	Barbara
Capacity (bpp)	0.019	0.019	0.019	0.019	0.019	0.012
$PSNR$ (dB)	62.722	61.770	62.510	62.947	62.137	66.092
$MSSIM$	1.000	1.000	1.000	1.000	1.000	1.000
Capacity (bpp)	6.732	6.732	6.732	6.732	6.732	6.736
$PSNR$ (dB)	36.077	36.368	36.444	36.519	36.436	36.302
$MSSIM$	0.870	0.872	0.923	0.858	0.876	0.932
AVR $PSNR$ (dB)	49.399	49.096	49.477	49.733	49.287	51.197
AVR $MSSIM$	0.935	0.936	0.962	0.929	0.938	0.966

of the Baboon and Barbara images with complex texture, even better than the effect of the smoothing image. When the embedding capacity is bigger, the $PSNR$ value is more than 36 dB, and it is more stable. AVR $PSNR$ is the average value between the smaller $PSNR$ and the maximum $PSNR$, and this shows that the perceptual quality is also very good. AVR $MSSIM$ is the average value between the smaller $MSSIM$ and the maximum $MSSIM$, The values of AVR $MSSIM$ are above 0.929, and this shows that the perceptual quality is also very good.

In Table 3, this capacity is the minimum embedding capacity and the maximum embedding capacity in the first row and the third row. In theory, the original cover image is enlarged three times $(512 \times 3) \times (512 \times 3)$ =1536 × 1536 to embed the secret information. With the embedding process (Section 3.1) shows that the cover's 4 low bits are used to embed secret data for each original pixel and a pixel to be interpolated, and embedded three times, because of the three-color components are embedded in the same amount of information. Therefore, the essence embedding capacity of each color component is (1536/2) × (1536/2) =768 × 768 bits =2.25 bpp, which can get the secret information embedded in a total of three-color components is 2.25 × 3=6.75 bpp, so the maximum embedding capacity in the actual test (6.732 bpp) can be obtained.

4.3. **Compared with The Existing Heterogeneous Latest Algorithm.** In recent years, there are many popular algorithms such as histogram shifting, interpolation expansion and lossless compression, of which embedding capacities are almost limited. The embedding capacity of the interpolation algorithm is higher than algorithms mentioned above. In this paper, in order to solve the problem that the degradation of the perceptual quality caused by the modification of the pixel value, the improved bicubic interpolation algorithm is used to improve the embedding capacity and perceptual quality. In order to show the superiority of the proposed algorithm compared with other types of embedding algorithms, the proposed algorithm is compared with Liu [12], Lu [13], Pan [15] and Li [10] as shown in Fig. 4.

Fig. 4 is the variation curve of the $PSNR$ value when the embedding capacity is less than 3.0 bpp. The experimental results show that the embedding capacity of the proposed algorithm is much higher than other existing algorithms, and it can also be seen from the curves of the above six figures in Fig. 4, the proposed algorithm is consistent with the curve changes in cover images of six different images, and the performance is very stable too. Although the $PSNR$ in [10] is higher than the proposed algorithm when the embedding capacity is less than 1.0 bpp as shown in Fig. 4(a), Fig. 4(b), Fig. 4(e) and Fig. 4(f), with the increase of the embedding capacity, the $PSNR$ in [10] decreases obviously, while the proposed algorithm is still very stable. Therefore, the embedding capacity in [10] is limited, the maximum can only reach 2.5 bpp, but the proposed algorithm can reach 6.732 bpp, which is more suitable for the RDH with high capacity.



(a) Lena (b) Airplane (c) Baboon

(d) Boat (e) Peppers (f) Barbara

FIGURE 4. Performance comparison of the proposed algorithm.

In order to show the superiority of the proposed algorithm further, the proposed algorithm is compared with Li [9], Li [10], and Ou [11], the variation of the $PSNR$ value when the embedding capacity is 50,000 bits is shown in Table 4.

TABLE 4. The $PSNR$ of different algorithm embedding in the same secret data

Cover image	Li [9]	Li [10]	Ou [11]	Proposed
Lena	55.75	54.63	56.23	57.94
Airplane	58.79	58.55	60.13	60.24
Baboon	–	50.87	50.83	58.33
Boat	–	–	–	58.21
Peppers	–	52.60	54.03	58.97
Barbara	55.16	55.69	57.01	61.29

As can be seen from Table 4, with the same embedding capacity of the secret data, the $PSNR$ value of the proposed algorithm is higher, which shows that the proposed algorithm is suitable not only for high capacity RDH, but also for low capacity RDH.

4.4. **Compared with The Existing Similar Algorithms.** In order to show the superiority of the proposed algorithm more comprehensively, the proposed algorithm is compared with existing similar algorithms Jung [17], Wang [19], Lu [20], Govind [21], and Vigila [22], which is shown in Table 5.

The embedding capacity and perceptual quality of this algorithm are better than that of the interpolation expansion algorithm by Jung [17], Lu [20], and Govind [21]. While the embedding capacity of this algorithm is far greater than that of the interpolation expansion algorithm by Wang [19] and Vigila [22], the perceptual quality is still good. For the same algorithm, when the same amount of the secret data of the image is embedded, the perceptual quality of the Baboon images with complex texture by the interpolation expansion algorithm of Wang [19], Lu [20] and Vigila [22] has a significant degraded. However, the proposed algorithm is very good at maintaining the good perceptual quality. Overall, the other algorithms have a common character. Compared with that of smoothed

Table 5. The comparison of existing similar algorithms

Method	Performance	Lena	Airplane	Baboon	Boat	Peppers	Barbara
Jung [17]	Capacity (bits)	589,824	589,824	589,824	589,824	589,824	–
	PSNR (dB)	37.56	37.68	37.54	37.48	37.50	–
Wang [19]	Capacity (bits)	71,191	87,301	24,855	–	66,934	40,383
	PSNR (dB)	48.80	48.94	48.50	–	48.75	48.59
Lu [20]	Capacity (bits)	249,763	246,811	185,940	227,687	–	–
	PSNR (dB)	33.923	33.614	28.392	30.373	–	–
Govind [21]	Capacity (bits)	250,343	247,297	–	233,918	–	–
	PSNR (dB)	34.10	33.77	–	31.60	–	–
Vigila [22]	Capacity (bits)	85,960	85,960	85,960	–	85,960	–
	PSNR (dB)	48.76	48.32	47.89	–	48.46	–
Proposed	Capacity (bits)	607,500	607,500	607,500	607,500	607,500	607,500
	PSNR (dB)	40.63	40.85	41.13	41.15	41.26	43.18

Lena and Airplane image, the perceptual quality of the Boat, Peppers, Barbara and Baboon image of complicated texture appeared the degradation. However, the perceptual quality of this algorithm has not degraded, but improved. This shows that this algorithm has higher precision and better perceptual quality for the stego image with complex texture, which is suitable not only for color image with smooth, but also for the color image with texture.

5. **Conclusions.** We proposed a novel high capacity RDH algorithm for color images based on bicubic interpolation extension. Compared with many existing RDH algorithms, the basic principle applies the redundant space of image to embed the secret data, but the embedding capacity of the proposed method is 4$\sim$5 times as much as they are. The perceptual quality is generally higher than existing algorithms. The main reasons are: 1) the algorithm expanded 3 times to the redundant space for embedding secret data on the original cover image, so the space of embedding secret data is very high; 2) the algorithm in this paper embeds secret data into the edge interpolation pixel, a reference pixel and does not embed the location map. It further increases the embedding capacity; 3) the algorithm in this paper predicts intermediate interpolation pixel value more accurately by using adjacent 16 pixel value, and the perceptual quality is better; 4) it can realize adaptive embedding capacity according to the interpolation of multiple k. The receiver does not need any additional information to extract the secret data and restore the original cover image. Further research is planned is consider the security, anti-attack, embedded capacity, perceptual quality and other factors, so that all the performance can achieve a better effect.

Acknowledgment. This work is supported by the National Natural Science Foundation of China (No. 61363078), the Natural Science Foundation of Gansu Province of China (No. 1310RJYA004). The authors would like to thank the anonymous reviewers for their helpful comments and suggestions.

REFERENCES

[1] C. W. Lee and W. H. Tsai, A lossless large-volume data hiding method based on histogram shifting using an optimal hierarchical block division scheme, *Journal of Information Science and Engineering*, vol. 27, no. 4, pp. 1265–1282, 2011.

[2] S. Hiary, I. Jafar, and H. Hiary, An efficient multi-predictor reversible data hiding algorithm based on performance evaluation of different prediction schemes, *Multimedia Tools and Applications*, vol. 76, no. 2, pp. 2131–2157, 2017.

[3] A. Nikolaidis, Low overhead reversible data hiding for color JPEG images, *Multimedia Tools and Applications*, vol. 75, no. 4, pp. 1869–1881, 2016.

[4] L. R. Mathews and V. A. C. Haran, Histogram shifting based reversible data hiding using block division and pixel differences, *Proc. of the IEEE International Conference on Communication and Computational Technologies*, Kanyakumari, pp. 937–940, 2014.

[5] W. M, Zhang, X. C, Hu, and X. L. Li, Recursive histogram modification: establishing equivalency between reversible data hiding and lossless data compression, *IEEE Transactions on Image Processing*, vol. 22, no. 7, pp.2775–2785, 2013.

[6] Z. Y. Xiong and T. F. Jiang, Reversible data hiding using prediction error difference expansion without location map, *Application Research of Computers*(in Chinese), vol. 27, no. 3, pp. 1015–1018, 2010.

[7] M. Liu, H. S. Seah, and C. Zhu, Reducing location map in prediction-based difference expansion for reversible image data embedding, *Signal Processing*, vol. 92, no. 3, pp. 819–828, 2012.

[8] C. F. Lee, C. C. Chang, and P. Y. Pai, An adjustable and reversible data hiding method based on multiple-base notational system without location map, *Journal of Information Hiding and Multimedia Signal Processing*, vol. 6, no. 1, pp. 1–28, 2015.

[9] X. Li, J. Li, and B. Li, High-fidelity reversible data hiding scheme based on pixel-value-ordering and prediction-error expansion, *Signal Processing*, vol. 93, no. 1, pp. 198–205, 2013.

[10] J. Li, X. Li, and B. Yang, Reversible data hiding scheme for color image based on prediction-error expansion and cross-channel correlation, *Signal Processing*, vol. 93, no. 9, pp. 2748–2758, 2013.

[11] B. Ou, X. Li, and Y. Zhao, Efficient color image reversible data hiding based on channel-dependent payload partition and adaptive embedding, *Signal Processing*, vol. 108, pp. 642–657, 2015.

[12] R. Liu, R. R. Ni, and Y. Zhao, A reversible data hiding based on adaptive prediction technique and histogram shifting, *Proc. of the Summit and Conference on Asia-Pacific Signal and Information Processing Association*, Siem Reap, pp. 1–6, 2014.

[13] Y. Y. Lu and H. C. Huang, Adaptive reversible data hiding with pyramidal structure, *Vietnam Journal of Computer Science*, vol. 1, no. 3, pp. 179–191, 2014.

[14] D. S. Fu, Z. J. Jing, and S. G. Zhao, Reversible data hiding based on prediction-error histogram shifting and EMD mechanism, *AEU - International Journal of Electronics and Communications*, vol. 68, no. 10, pp.933–943, 2014.

[15] Z. Pan, S. Hu, and X. Ma, Reversible data hiding based on local histogram shifting with multi-layer embedding, *Journal of Visual Communication and Image Representation*, vol. 31, pp. 64–74, 2015.

[16] W. Hong and T. S. Chen, Reversible data embedding for high quality images using interpolation and reference pixel distribution mechanism, *Journal of Visual Communication and Image Representation*, vol. 22, no. 2, pp. 131–140, 2011.

[17] K. H. Jung and K. Y. Yoo, Steganographic method based on interpolation and LSB substitution of digital images, *Multimedia Tools and Applications*, vol. 74, no. 6, pp. 2143–2155, 2014.

[18] X. Q. Zhang, Z. R. Sun, Z. J. Tang, and C. Q. Yu, Reversible information hiding method based on parabola interpolation, China, CN103501400A[P], 2014.

[19] X. T. Wang, C. C. Chang, and T. S. Nguyen, Reversible data hiding for high quality images exploiting interpolation and direction order mechanism, *Digital Signal Processing*, vol. 23, no. 2, pp.569–577, 2013.

[20] T. C. Lu, C. C. Chang, and Y. H. Huang, High capacity reversible hiding scheme based on interpolation, difference expansion, and histogram shifting, *Multimedia Tools and Applications*, vol. 72, no. 1, pp. 417–435, 2014.

[21] P. V. S. Govind, M. Wilscy, A new reversible data hiding scheme with improved capacity based on directional interpolation and difference expansion, *Procedia Computer Science*, vol. 46, pp. 491–498, 2015.

[22] S. M. C. Vigila and K. Muneeswaran, Hiding of confidential data in spatial domain images using image interpolation, *International Journal of Network Security*, vol. 17, no. 6, pp.722–727, 2015.

[23] N. Ajeeshvali and B. Rajasekhar, Steganography based on integer wavelet transform and bicubic interpolation, *International Journal of Image Graphics and Signal Processing*, vol. 4, no. 12, pp. 26–33, 2012.

[24] A. Al-Gindy, H. Al-Ahmad, R. Qahwaji and A. Tawfik, Watermarking of colour images in the DCT domain using Y channel, *Proc. of the IEEE/ACS International Conference on Computer Systems and Applications (AICCSA 2009)*, IEEE, Rabat, Morocco, pp. 1025–1028, 2009.

[25] K. Santhi and A. M. N. Kumar, Biometrics based steganography using circular folding in DWT domain, *International Journal of Computer Applications*, vol.61, no.10, pp. 47–51, 2013.