**Comparative study of Interpolation Algorithms for Image Reconstruction**

YuChen Mei1a†, BaoKang Shao2b†, Zeyu Zheng3c†

1 Department of Computer Application Enfineering, Macao University of Science and Technology macao 999078, China

2 Department of Computer Application Engineering, Guangzhou Vocational and Technical University of Science and Technology guangzhou 510000, China

3 Department of Computer Application Engineering, School of East China Sea Science and technology, Zhejiang Ocean University 315300, China

a1604361948@qq.com

b[1054880404@qq.com](mailto:1054880404@qq.com)

[cMRMAX20001002@foxmail.com](mailto:cMRMAX20001002@foxmail.com)

†These authors contributed equally.

Abstract—As the visual basis of human perception of the world, image is an important means for human beings to obtain, express and transmit information. To ensure the transmission speed of three channel color images, they are often compressed into two-dimensional matrix first. In this scenario, how to realize high-quality color image reconstruction based on 2D pixel matrix has become a research hotspot. Much effort has been made to recover the image from the 2D matrix through interpolation algorithms, while their performance is still limited due to the fuzzy generated edges. In this paper, we focus on exploring the application boundary of different classical interpolation methods, and compare the RGB mean peak value, mean square error and signal-to-noise ratio. At the end of the article, the best method and corresponding improvement suggestions are put forward.

Keywords—Image reconstruction; interpolation algorithm; image processing

# 1. Introduction

At present, with the rapid development of digital image processing technology, the application area of image interpolation technology[1] is very broad, so it has important application prospect in remote sensing satellite meteorology, medical imaging, film and television, military and so on. However, in the process of image acquisition, due to the limitation of equipment manufacturing technology or interference from external factors, so the image resolution obtained is often lower than what people would expect visually. The resolution of the image determines how much information in the image can provide and degree of easy or difficulty in the recognizing objects in images, therefore, improving the resolution of images has become a research issue of great concern, there are three early image processing algorithms in the history of image processing research, they are bilinearity interpolation, colorimetric constant and gradient edge interpolation, this paper mainly studies the comparison of these three algorithms to image processing, to find out a better image processing effect of the algorithm.

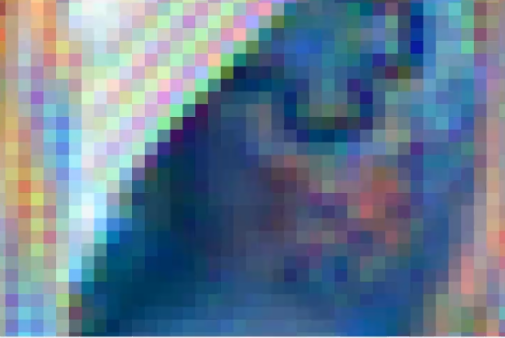
These three interpolation methods are widely used because of their simple implementation, among which the bilinear interpolation algorithm has high utilization rate in image processing. But bilinear interpolation algorithm will appear blurred edges (see Figure 1), reduce the image resolution and produce a sawtooth effect[2] across the boundary, although the colorimetric constant method is better than the bilinear interpolation method in image restoration, the edge sawtooth effect is not well improved because the edge problem is not considered, gradient edge interpolation algorithm considers the boundary problem separately, which well improves the restoration degree and edge sawtooth effect. Pictures 1 shows a comparison of bilinear interpolation with the original image and its edges. Colorimetric constant is to calculate all G components in the image by bilinear interpolation method and then use the adjacent pixel R and B components to calculate the image to be obtained. The gradient edge interpolation is based on the idea of gradient, that is, the gradient is detected before restoring the green channel, and the interpolation direction is determined according to the gradient size. The constant color difference method is used to calculate the red and blue information when the red and blue channels are restored.

In order to compare different image processing technology and finally present the effect, this paper for different classic image interpolation algorithm is a simulation, and experimental results for different style of image comparison, the purpose is to compare the pros and cons of each algorithm between sex, interpolation algorithm for follow-up researchers to improve optimization study to lay the foundation. In order to find out the three algorithms which algorithm is the best effect for image processing, several comparison methods are made. Five different images are prepared in maltab, and the Bayer filter algorithm is used to extract image color. Bilinear interpolation method, colorimetric constant method, and image processing based on gradient edge interpolation method are used respectively. Then the RGB mean value of the sample image and the RGB mean value of the image restored by the three algorithms are measured by the algorithm. And in the algorithm using signal-to-noise ratiop[3], mean square error[4] these two kinds of judgment basis, for comparison, through the comparison of objective data to select the three algorithms in the image processing effect of a better algorithm.

The structure of this paper is as follows: Chapter three introduces the concepts of these classical algorithms and the corresponding theoretical methods in detail. The fourth chapter introduces the realization process of these classical algorithms in MATLAB, and compares their experimental results and causes of these problems. The fifth chapter is the summary of the experimental results, and the author's ideas for the future optimization of the algorithm.



Original image Reconstruct through bilinear interpolation



|  |
| --- |
| The sawtooth effect at the right of reconstruced picture |
| Figure 1 Visualization of sawtooth effect after bilinear interpolation |

# Related work

A relatively simple algorithm is the Nearest neighbor interpolation algorithm [5]. When the picture is enlarged, the missing pixel is produced by utilizing the nearest native pixel. The principle is to select the pixel closest to the inserted pixel (x + U, y + V). Here, x and y is an integer while U and V is a decimal], Replaces the inserted pixel with the grayscale value of its pixel. The nearest neighbor interpolation method has a small amount of computation, but it may lead to the discontinuity of image gray level and obvious jagged changes.

In two-dimensional space, bicubic interpolation[6] is the most commonly used interpolation method. In this method, the value of function f at point (x, y) can be obtained by the weighted average of the nearest 16 sampling points in the rectangular grid. Here, two polynomial interpolation cubic functions need to be used, one in each direction. Bicubic interpolation is a method for "interpolating" or increasing the number / density of "pixels" in an image. Interpolation techniques can efficiently increase graphic data, which can be used to expand the print area and improve resolution when printing or transmitting in other forms.

The inverse distance weight method[7] mainly depends on the power value of the inverse distance. The power parameter can control the influence of the known points on the interpolation based on the distance from the output point. The power parameter is a positive real number, and the default value is 2. (generally, a value of 0.5 to 3 can obtain the most reasonable result). The closest point can be further emphasized by defining a higher power value. Therefore, the adjacent data will be more affected and the surface will become more detailed (less smooth).

# Algorithm

*3.1 Internal relationship of selected three algorithms*

As one of the commonly used interpolation methods, bisexual interpolation has fast calculation speed, but the image restored by this algorithm has poor scaling quality, blurred edges and reduced resolution, and sawtooth fringes will be generated at the edges. The colorimetric constant method is modified on the basis of bilinear, so that the resolution of the image restored by the colorimetric constant method is better than that of the bilinear interpolation method. However, when the G component is very small, the noise has a great impact on the image restoration, and the boundary problem has not been well solved. Gradient edge interpolation algorithm is an improved algorithm for the boundary problem in bilinear interpolation method and colorimetric constant method. This algorithm better solves the edge problem of bilinear interpolation algorithm and colorimetric constant method. These three algorithms belong to the early algorithms proposed by people to restore image resolution, and are widely used.

*3.2 Gradient edge interpolation Algorithm*

Gradient edge interpolation method[8] can overcome the problem of edge blur caused by bilinear interpolation algorithm. This algorithm has two processing ideas. The first is based on the idea of gradient. This algorithm first compares the size of the gradient in the horizontal direction and the vertical direction. If the value in the horizontal direction is small, it will be interpolated in the horizontal direction, otherwise it will be interpolated in the vertical direction. The second processing idea is the idea of constant color difference. When restoring the red and blue channels, the constant color difference in a small neighborhood is used to calculate the red and blue information.Calculation steps of interpolation based on gradient idea: Let the absolute value of the gradient in the horizontal direction beα, The gradient value in the vertical direction is β.

Hibbard method: this method is to subtract the front and rear g components in the horizontal direction to obtain the absolute value to form the gradient in the horizontal direction, and then subtract the upper and lower g components to obtain the absolute value to form the gradient in the vertical direction.

Laroche method: this method is to take three closest components in the horizontal direction, multiply the middle R component by 2 minus the values of the left and right *R* components, take the absolute value to form the gradient value in the horizontal direction, then take three closest *R* components in the vertical direction, multiply the middle *R* component by 2 minus the values of the left and right *R* components, and take the absolute value to form the gradient value in the vertical direction,

(2)

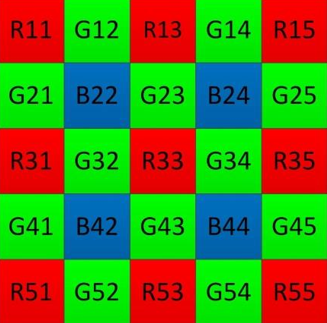


Figure 2 Bayer filter

if α<β Then there is little possibility of boundary in the horizontal direction, and the interpolation is carried out along the horizontal direction. At this time, G33 is :

(3)

if β<α Then there is little possibility of boundary in the vertical direction, and the interpolation is carried out along the vertical direction. At this time, G33 is:

(4)

The idea of constant color difference is used to restore the red and blue channels Color difference generally refers to the use of the color difference R-G between red and green, the color difference B-G between blue and green, and if the color difference is constant, it is considered that the color difference is constant in the small smooth area of the image.The calculation method is as follows:

(5)

there

(6)

What is shown in Figure 2 is :

(7)

*3.3 linear interpolation*

Firstly, the linear difference is introduced. Linear interpolation refers to the interpolation method in which the interpolation function is a polynomial, and the interpolation error on the interpolation node is zero. Linear interpolation can be used to approximate and replace the original function, and can also be used to calculate the values that are not in the table in the process of looking up the table. As shown in the figure, it is now known that the coordinates of the two points of y = f (x) are (x0, Y0), (x1, Y1) respectively. Now, given any X in the interval (x0, x1), how to find y, the linear interpolation method uses the Y value of the red point in the figure to replace the y value of F (x). Assuming that the red dot coordinates on the line at X are (x, y), then y is approximately equal to y.

According to the figure, the formula can be obtained:

(8)

Expressed by Y0 and Y1

(9)

Regard the fraction as the weight coefficient.

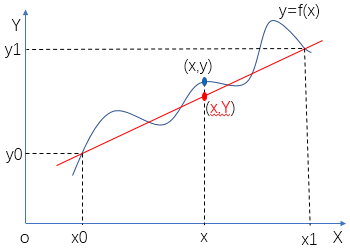


Figure 3 Bilinear Interpolation

Bilinear interpolation[9], also known as bilinear interpolation. Mathematically, bilinear interpolation is a linear interpolation extension of the interpolation function with two variables. Its core idea is to perform linear interpolation in two directions respectively. As an interpolation algorithm in numerical analysis, bilinear interpolation is widely used in signal processing, digital image and video processing. Mathematically, bilinear interpolation is a linear interpolation extension of the interpolation function with two variables. Its core idea is to perform linear interpolation in two directions respectively.

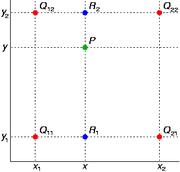
[](http://zh.wikipedia.org/wiki/File:Bilinear_interpolation.png)

Figure 4 Bilinear interpolation

In the figure: red data points and green points to be interpolated .If we want to get the value of the unknown function f at point P = (x, y), suppose we know the value of the function f at four points, Q11 = (x1, Y1), Q12 = (x1, Y2), Q21 = (X2, Y1) and Q22 = (X2, Y2). Firstly, linear interpolation is carried out in the direction of x to obtain

where

(10)

Then linear interpolation is carried out in the direction of y to obtain

(11)

This gives the desired result f (x, y),

(12)

Bilinear interpolation is also called first-order interpolation. Its interpolation principle is that the pixel value of the point to be inserted takes the linear interpolation in the horizontal and vertical directions of the pixel values of the four adjacent points in the original image, that is, the corresponding weight is determined according to the distance between the point to be sampled and the surrounding four adjacent points, so as to calculate the pixel value of the point to be sampled. The image processed by this algorithm will produce many new pixel values, which are mainly obtained by the gray value of the pixels around the interpolation

point through interpolation operation..

As shown in Figure 1, R and B components on G pixels:

(13)

B and G components on R pixel:

(14)

Because this algorithm does not consider the influence of the change rate of gray value of adjacent points, it has the property of low-pass filter, which will lose the important details of the enlarged image and make the image blurred

*3.4 Cok Algorithm*

Cok algorithm[10] uses some bright knowledge to prompt: from the perspective of physical optics, for a small smooth neighborhood of the same object, the proportion of light intensity of three color channels will not change suddenly. In normal natural scenes or ordinary photos, in local areas, the proportion of the three channels is basically the same. The R / G of any area is approximately equal to that of the adjacent lattice, and so is B / G. Red than green and blue than green are considered to be non mutative.

(15)

In this case, we can achieve a certain degree of fidelity by bringing bright knowledge into interpolation.

Steps of cok algorithm:

1. Calculate all G components of the picture by bilinear interpolation:

(16)

1. The R and B components of the pixels to be calculated are calculated by using the R and B components of adjacent pixels:

(17)

1. Multiple adjacent points are averaged:

(18)

# Experiments and Performance Analysis

The following is the comparison between the original R, G and B components of the image signal-to-noise ratio, mean square error and the sample image and the R, G and B components after the three algorithms.

In the experiment, five sample images are selected for comparison, and the Bayer filter algorithm is used for RGB extraction to generate five Bayer images. The three algorithms in this paper are used for interpolation to process the color Haiyuan of the five images. The visual effect image can be seen below:

Fig. 5.1.1, 5.2.1, 5.3.1, 5.4.1, 5.5.1 are sample images, FIG. 5.1.2, 5.2.2, 5.3.2, 5.4.2, 5.5.2 are Bayer filter images, FIG. 5.1.3, 5.2.3, 5.3.3, 5.4.3, 5.5.3 are bilinear interpolation algorithms, FIG. 5.1.4, 5.2.4, 5.4.4, 5.5.4 are colorimetric constant methods, and Fig. 5.1.5, 5.2.5, 5.3.5, 5.5.5 are gradient edge interpolation methods. See Table 1, 2.3, 4 and 5 for color reduction data.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 样本1 | 条纹bilin | cok1 | 条纹梯度 |
| FIG 5.1.1 | FIG 5.1.2 | FIG 5.1.3 | FIG 5.1.4 | FIG 5.1.5 |
| 汽车1 | 汽车2 | 汽车bilin | 汽车cok | 汽车梯度 |
| FIG 5.2.1 | FIG 5.2.2 | FIG 5.2.3 | FIG 5.2.4 | FIG 5.2.5 |
| 电脑1 | 电脑2 | 电脑blin | 电脑cok | 电脑梯度 |
| FIG 5.3.1 | FIG 5.3.2 | FIG 5.3.3 | FIG 5.3.4 | FIG 5.3.5 |
| 人脸1 | 人脸2 | 人脸bilin | 人脸cok | 人脸梯度 |
| FIG 5.4.1 | FIG 5.4.2 | FIG 5.4.3 | FIG 5.4.4 | FIG 5.4.5 |
| 樱桃1 | 樱桃2 | 樱桃bilin | 樱桃cok | 樱桃梯度 |
| FIG 5.5.1 | FIG 5.5.2 | FIG 5.5.3 | FIG 5.5.4 | FIG 5.5.5 |
| Figure 5 Visualization of different interpolation | | | | |

Tab 1 Results of different methods on stripe

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| RGB component mean | | | | mean square error | | | signal-to-noise ratio | | |
| Original | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation |
| R:95.283 | R:95.1989 | R:93.5297 | R:95.7078 | 199.3947 | 185.1819 | 85.335 | 25.1337 | 25.4548 | 28.8195 |
| G:95.283 | G:95.3617 | G:95.3617 | G:95.2394 |
| B:95.283 | B:95.5991 | B:94.4202 | B:95.6842 |

Tab 2 Results of different methods on car

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| RGB component mean | | | | mean square error | | | signal-to-noise ratio | | |
| Original | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation |
| R:48.197 | R:48.0789 | R:48.3522 | R:48.5599 | 13.1507 | 10.1715 | 5.6244 | 36.9413 | 38.057 | 40.6301 |
| G:52.653 | G:52.7026 | G:52.7026 | G:52.7891 |
| B:57.299 | B:57.3861 | B:57.3754 | B:57.522 |

Tab 3 Results of different methods on computer

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| RGB component mean | | | | mean square error | | | signal-to-noise ratio | | |
| Original | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation |
| R:171.15 | R:168.4202 | R:171.512 | R:169.2348 | 94.9994 | 49.1303 | 16.2432 | 28.3536 | 31.2173 | 36.0241 |
| G:183.97 | G:183.9879 | G:183.9879 | G:182.7803 |
| B:184.56 | B:181.5541 | B:184.473 | B:183.0667 |

Tab 4 Results of different methods on face

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| RGB component mean | | | | mean square error | | | signal-to-noise ratio | | |
| Original | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation |
| R:125.1406 | R:125.4485 | R:124.4904 | R:124.9769 | 117.1131 | 89.868 | 49.9404 | 27.4447 | 28.5948 | 31.1463 |
| G:106.9832 | G:107.0569 | G:107.0569 | G:107.4869 |
| B:114.7243 | B:114.7813 | B:112.5031 | B:114.3522 |

Tab 5 Results of different methods on cherry

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| RGB component mean | | | | mean square error | | | signal-to-noise ratio | | |
| Original | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation | Bilinear interpolation | Colorimetric constant | Gradient edge interpolation |
| R:207.0868 | R:207.2528 | R:206.0315 | R:207.9737 | 61.6353 | 51.7216 | 6.2895 | 30.2325 | 30.9941 | 40.1447 |
| G:193.4731 | G:193.4998 | G:193.4998 | G:194.9102 |
| B:202.2066 | B:202.2098 | B:199.5494 | B:202.4744 |

For the mean value of RGB components, the three algorithms have different differences in different image environments: in the fringe image environment, the mean value of RGB components of samples is 95.283, the corresponding mean values of bilinear interpolation RGB components are 95.1989, 95.3617 and 95.5991 respectively, and the mean values of RGB components of corresponding colorimetric constant method are 93.5297, 95.3617 and 94.4202 respectively, The mean values of RGB components of the corresponding gradient edge interpolation method are 95.7078, 95.2394 and 95.6842 respectively. In the automobile picture environment, the RGB mean values of samples are 48.1979, 52.6513 and 57.2919 respectively, the corresponding bilinear interpolation RGB component mean values are 48.0789, 52.7026 and 57.3861 respectively, the corresponding colorimetric constant RGB component mean values are 48.3522, 52.7026 and 57.3754 respectively, and the corresponding gradient edge interpolation RGB component mean values are 48.5599, 52.7891 and 57.522 respectively. In the computer picture environment, the RGB mean values of samples are 171.1523, 183.9786 and 184.5605 respectively, the corresponding bilinear interpolation RGB component mean values are 168.4202, 183.9879 and 181.5541 respectively, the corresponding colorimetric constant RGB component mean values are 171.512, 183.9879 and 184.473 respectively, and the corresponding gradient edge interpolation RGB component mean values are 169.2348, 182.7803 and 183.0667 respectively. In the face image environment, the RGB mean values of samples are 125.1406, 106.9832 and 114.7243 respectively, the corresponding bilinear interpolation RGB component mean values are 125.4485, 107.0569 and 114.7813 respectively, the corresponding colorimetric constant RGB component mean values are 124.4904, 107.0569 and 112.5031 respectively, and the corresponding gradient edge interpolation RGB component mean values are 124.9769, 107.4869 and 114.3522 respectively. In the cherry picture environment, the mean value of R component is the bilinear interpolation method. The mean value of R component in the restored picture is the closest to the mean value of R component in the sample, while the mean value of G component is the same as that of G component in the restored picture by bilinear interpolation method and colorimetric constant method. Similarly, the mean value of B component in bilinear interpolation method is the closest to the mean value of B component in the sample. By comparing the above five groups of data, it is found that there is little difference between the RGB mean of the three different algorithms and the RGB mean of the sample data in different picture environments. Therefore, through data analysis, it can be concluded that it is not rigorous to use the RGB mean as the judgment basis for the image restoration effect on the algorithm.

Therefore, the team hopes to further judge the advantages and disadvantages of the three algorithms for image restoration by comparing the signal-to-noise ratio and mean square error of the three algorithms for five sample images. In the above five groups of data, in the fringe image environment, the signal-to-noise ratio of bilinear interpolation method is 25.1337 and the mean square error is 199.3947. The signal-to-noise ratio of colorimetric constant method is 25.4548 and the mean square error is 185.1819. The signal-to-noise ratio of gradient edge interpolation method is 28.8195 and the mean square error is 85.335. In the four groups of color images, the signal-to-noise ratio of bilinear interpolation is 36.9413 for cars, 28.3536 for computers, 27.4447 for faces and 30.2325 for cherries. The mean square error is 13.1507 for cars, 94.9994 for computers, 117.1131 for faces and 61.6353 for cherries. The signal-to-noise ratios of the constant colorimetric method in the four groups of color images are car: 38.057, computer: 36.0241, face: 31.1463, cherry: 30.9941, and the mean square error is car: 10.1715, computer: 49.1303, face: 89.868, cherry: 51.7216. In contrast, the signal-to-noise ratio of gradient edge interpolation method in four groups of color images is car: 40.6301, computer: 31.2173, face: 28.5948, cherry: 40.1447, and the mean square error is car: 5.6244, computer: 16.2432, face: 49.9404, cherry: 6.2895. It can be seen from the above that the effect of the three algorithms on restoring the resolution varies in different image environments, but the bilinear interpolation method can be obtained from the data of the three algorithms. As the image restoration algorithm proposed earlier, its effect on the resolution of image restoration is not as good as the other two algorithms, and the effect of colorimetric constant method on restoring the image is in the middle of the three methods, The gradient edge interpolation method is one of the three algorithms with better image restoration effect. It can be seen from the data that the mean square error of bilinear interpolation method is large and the signal-to-noise ratio is small. Compared with bilinear interpolation method, the mean square error and signal-to-noise ratio of colorimetric constant method are reduced and increased to a certain extent, Gradient edge interpolation is the algorithm with the lowest mean square error and the highest signal-to-noise ratio among the three algorithms, which shows that gradient edge interpolation has a better effect in image restoration.

# 5. Conclusion

In this work, we analyzed and compared the three classic color interpolation algorithms of Bilinear, Cok and Hibbard. According to the data comparison and analysis, we can see that the bilinear interpolation method has the largest mean square error and the smallest signal to noise ratio, the gradient edge interpolation method has the smallest mean square error and the largest signal to noise ratio, while the color constant method is better than the bilinear interpolation method and worse than the gradient edge interpolation method, from the comparison of each figure, we can see that the restoration degree of the bilinear interpolation method will have the problem of inaccurate restoration of a small number of pixels, and the bilinear interpolation has a blurred edge area, and the gradient edge interpolation method has a zipper effect. The linear interpolation has blurred edge areas and zipper effect, while the color constancy method has higher restoration than the bilinear interpolation method, but still has blurred edge areas and zipper effect, while the gradient edge interpolation algorithm can restore the sample image to a greater extent and improve the zipper effect, but there is still a small part of the pixel blurring phenomenon. This paper finds out the characteristics of each of the three linear interpolation methods by comparing them.

# 6. References

[1] Hang Wei Application of image interpolation technology in image processing [D] Changchun University of technology

[2] Guo Xiaowei, Wang xueshui, Yu Gang Design of anti aliasing unit in image scaling [J] Computer knowledge and technology: academic exchange, 2012

[3] Wang Yinfei, Zhang Yuchen ICCD SNR model [J] Technological innovation and application, 2018 (32): 2

[4] Tian Xiang Mean square error analysis of optimal approximation of function [J] Journal of School of mechanical engineering, Hohai University, 1997

[5] Shen Jia Simulation of classical interpolation algorithm [J] Science and technology information, 2009 (33): 2

[6] Pang Zhiyong, Tan Hongzhou, Chen Dihu An improved low-cost adaptive bicubic interpolation algorithm and its VLSI implementation [J] Journal of automation, 2013 (4): 11

[7] Yu Xiaodong, Wu Ying, he Lamei Improvement and comparison of inverse distance weighted gridding interpolation algorithms [J] Journal of Engineering Geophysics, 2013, 10 (6): 5

[8] Li Haihua, fan Juan Research on adaptive edge detection algorithm based on gradient [J] Journal of Henan University of Technology (NATURAL SCIENCE EDITION), 2013, 032 (001): 76-79

[9] Bai Xiangjun Bilinear interpolation algorithm and its parallel implementation [J] Computer knowledge and technology: Academic Edition, 2014 (9x): 3

[10]Zhang Yuhao Research on Bayer image de mosaic algorithm [D] School of computer science and technology, June 2020