COMPARISON OF INTERPOLATION METHODS WHEN ACHIEVING SUPER-RESOLUTION OF IMAGES BASED ON THE ANALYSIS OF SEVERAL FRAMES

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Abstract. Increasing the resolution based on the use of multiple frames of the same object leads to additional errors. These errors are the result of errors in determining the position of frames, as well as the result of interpolation inaccuracy. In this paper, only errors caused by interpolation are analyzed. We consider the dependence of errors on the number of frames used, the type of interpolation, the type of the original image. It is shown that after averaging over the positions of individual frames, the key dependencies are the dependence of errors on the number of frames and the type of interpolation. It is shown that it does not make sense to analyze interpolation errors immediately after the interpolation procedure. After the required spectral filtering procedure, relatively small interpolation errors will increase significantly. Change and the type of dependence of errors on the number of frames. Therefore, it is advisable to draw the main conclusions based on the analysis of interpolation errors after the filtering procedure. From the point of view of error minimization, it is preferable to use interpolation by a cubic spline and spectral interpolation.

Keywords: interpolation, superresolution, image, frame

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1. INTRODUCTION

Increasing the resolution of images obtained by aircraft is an important task. A detailed review of ultra-high resolution (super resolution) methods was given in [1] for reconstructing an image based on several low-resolution frames. The main source of additional information for super-resolution is a number of images of the same object, slightly shifted in successive frames. The pixels of the camera that receives the image have a non-zero size; therefore, the observed pixel value does not correspond to the value at a specific point on the real image, but is averaged over some neighborhood of the point. The object is shifted, as a rule, by a non-integer

number of pixels, therefore, it is possible to use the information of several frames to build a single high-resolution image.

Fig. 1 shows the scheme of the super-resolution method, which consists of three stages. At the first stage (Fig. 1, numbers 1, 2 and 3) it is determined the shift of low-resolution frames. After determining the frame shift with pixel accuracy, they proceed to the stage of determining the sub-pixel shift (Fig. 1, figure 4). At the same time, the definition of sub-pixel frame shift can be performed in different ways, in particular, using neural networks [2], with a preliminary increase in frames and image search, which, when reduced with taken a motion into the account, will give the minimum total quadratic deviation from the original low-resolution images [3, 4], by directly determining the sub-pixel offset from the position of the maximum of the cross-correlation function of image frames [5]. At the final stage, the existing series of frames are combined with known sub-pixel offsets, which is performed using interpolation [1] (Fig. 1, image 5).

Fig. 1. The scheme of the method of super-resolution. The numbers 1, 2, 3 denote low-resolution frames. The number 4 denotes an image of low-resolution frames combined with subpixel offsets. The number 5 corresponds to the interpolated image obtained from image 4.

During of such processing some errors occur, associated with the definition of sub-pixel displacements, and with the properties of the interpolation method itself. The evaluation of errors arising from this is an important, urgent task [6]. Indeed, it is not enough in one way or another (by the method) to obtain an image of an increased resolution, it is also necessary to find out to what extent the result is adequate to reality.

Information on subpixel offsets can be obtained from the resulting low-resolution frames and measurement conditions. For example, if you know the speed and direction of the photo camera, you can ignore the presence of vibration and other uncontrolled factors. Therefore, the magnitude of errors in determining sub-pixel frame offsets largely depends on the measurement conditions controlled by the person. At the same time, interpolation errors depend both on the interpolation method, on the set of sub-pixel offsets, and on the resulting image. Previously, interpolation error estimates were made only when using test images or any assumptions about the properties of images [1, 5-11]. It is assumed that the magnitude of errors for the selected interpolation method depends only on the type of image. At the same time, the algorithm proposed in [7] could allow the creation of a method

to evaluate the interpolation errors of experimental data without using test images and the expected properties of the resulting image. The method [7] does not allow to calculate the exact value of the interpolation error, it can only be used to estimate the possible interpolation error.

The paper [15] analyzed the possibilities of such a method for estimating interpolation errors without using test images and the expected properties of the resulting image to estimate errors in the synthesis of images with superresolution obtained using several frames.

It should be noted that the magnitude of interpolation errors does not determine the magnitude of image reconstruction errors with an increased resolution compared to the original frames. The fact is that after receiving an interpolated image, spectral filtering is performed to improve the quality of the reconstructed high-resolution image [15]. During this filtering, the magnitude of the errors increases. However, depending on the type of interpolation, the same magnitude of interpolation errors can lead to different errors after filtering the interpolated images.

In this paper, we examine the dependence of the magnitude of the difference between the reconstructed image and the number of frames used and the type of interpolation.

We will consider the following interpolation methods:

- interpolation of inverse weighted distances (IWD) [11] used in cartography;
- interpolation by a cubic spline [10, 16];
- spectral interpolation [17];
- linear interpolation based on triangulation [18].

2. BASIC ASSUMPTIONS

- The lens forming the image is ideal. The phenomenon of diffraction is absent. Only geometric optics is valid.
- The limitation of the resolution of images is determined only by the number of photosensitive elements (pixels) per unit area.
- Light-sensitive pixels are packed tightly and do not have gaps between them. Due to this condition, an image that contains small objects and narrow stripes can be fully restored, since there are no image elements that fall between the pixels.

- 4. The image within one pixel is averaged evenly.
- 5. Pixels are square.
- 6. Subpixel frame shift relative to each other is set.

3. THE FORMATION OF THE TEST IMAGE

The purpose of this item is to form a series of low resolution test images from a single high resolution image. A low-resolution image produces a low-resolution photosensitive matrix whose pixel sizes are N_p times larger than that of the test image. To get one frame, we need to average the test image over N_p pixels horizontally and vertically. Figure 2 shows the original (128×128 pixels) and averaged ($N_p = 4$) image of the “Bishkek 2,512” aerial photograph. The averaged image demonstrates the possible image quality with perfect recovery from N_p frames.

When forming a test image, suppose that individual frames are formed along the horizontal axis, but a sub-pixel offset occurs along both axes at the same time.

From the average test image to form one frame, we can take each N_p pixel horizontally and vertically. We start counting the pixels of the first frame from the upper left corner. The beginning of each subsequent frame occurs with a horizontal and vertical shift. The magnitude of the shift may not to be an integer one and to lay within the limits multiplied by N_p . To ensure no integer shift, interpolation must be applied. If the shift is greater than N_p , then we make a combination with pixel accuracy as in [5].

Thus, when modeling a quasi-continuous image, it is proposed to take a discretization step for each coordinate N_p times smaller than matrix photodetectors are formed. When processing a digital image (with a large, i.e., “single” step), it is

Fig. 2. The original image (a) is 128×128 pixels and averaged (b).

Fig. 3. Images: a) - the first frame; b) - the first $N = 5$ frames out of 16 located in series with each other.

proposed to consider as a super-resolution a return to this small step.

All the frames obtained in the above manner can be represented in the form of a general picture - Fig. 3 (fragment of Fig. 2b).

Upon receipt of Fig. 3, the matrix of shifts S_m of frames relative to the first frame was set:

At this stage, the formation of the test image is completed. Further we will use only Fig. 3b and Table 1.

4. INTERPOLATION
4.1. ONE TEST IMAGE

Based on the specified subpixel shifts S_m and a series of consecutive frames (Fig. 3b), you can use interpolation to obtain an image with a resolution larger than that on the original frames.

Fig. 4 presents the interpolation results obtained on the basis of 5 frames from the image of Fig. 3b.

Fig. 4 illustrates the fact that the image quality as a result of interpolation is weakly dependent on the type of interpolation. Table 2 shows the standard deviations of the images shown in Fig. 4 from the averaged source image presented in Fig. 2b.

Fig. 5 presents the graphs of the standard deviation (RMS) of interpolated (Fig. 5a) and filtered with the help of the Wiener filter [8] (Fig. 5b) images depending on the number of frames used.

The graphs shown in Fig. 5 show that the Wiener filter leads to an increase in the root-mean-square

Table 1.
The matrix of shifts of S_m frames relative to the first frame. 1 line - frame number. 2 and 3 line, respectively, the magnitude of the shifts in the horizontal and vertical in fractions of a pixel.

1	2	3	4	...
0	0.375	0.625	0.875	...
0	0.625	0	0.375	...

Fig. 4. The results of the interpolation of the image obtained from 5 frames Fig. 3b. The images shown in Fig. 4 are the result: a) - interpolation of inverse weighted distances (IWD); b) - interpolation by a cubic spline; c) - spectral interpolation; d) - linear interpolation based on triangulation.

error. This fact is illustrated with the data given in Table 2.

Fig. 5. Graphs of the standard deviation of interpolated - (a) and filtered - (b) images depending on the number of frames used. The graphs correspond to: IWD - red line, cubic spline - green line, spectral interpolation - blue line, linear interpolation - black line.

Table 2.

Root-mean-square deviations of images

	IWD	cubic spline	spectral interpolation	linear interpolation
Average Image	6.296	4.596	4.642	6.101
Filtered image	17.248	14.087	14.693	17.795

Fig. 6 shows images obtained from images of Fig. 4 using the Wiener filter.

Comparison of images in Fig. 4 and Fig. 6 allows us to conclude that the artifacts that appeared on the interpolated images depend on the type of interpolation used. It should be noted that the minimum standard deviation of the images is obtained with using spline interpolation and spectral interpolation.

Fig. 7 shows the deviations of the average deviation of the average resolution over 20 realizations of the low resolution Sm frames.

The graphs in Fig. 7 indicate that large standard deviations are caused by the use of IVR and linear interpolation. Smaller mean-square deviations are obtained using cubic spline and spectral interpolation.

The analysis of the graphs in Fig. 7 suggests that under the condition of rationing, the graphs of frame shifts averaged over different implementations

Fig. 6. Images obtained from images in Fig.4 using the Wiener filter. Images correspond to: a) - interpolation of inverse weighted distances (IWD); b) - interpolation by a cubic spline; c) - spectral interpolation; d) - linear interpolation based on triangulation.

Fig. 7. RMS graphs averaged over 20 implementations, interpolated - (a) and filtered - (b) images depending on the number of frames used. The graphs correspond to: IWD - red line, cubic spline - green line, spectral interpolation - blue line, linear interpolation - black line.

of the S_m matrix will weakly depend on the image and be determined by the type of interpolation.

4. 2. FIVE TEST IMAGES

Fig. 2 and 8 show the original test images used below to test this hypothesis.

Fig. 9 shows the deviations for the IVR in the case of the test images shown above (Fig. 2, Fig. 8).

Fig. 8. Additional test images.

Fig. 9. Graphs of normalized standard deviation, averaged over 20 S_m implementations for 5 images, are presented in Fig. 2 and Fig. 8. The graphs corresponding to the images are highlighted in color: Fig. 8a - red line, Fig. 8b - maroon line, Fig. 2a - blue line, Fig. 8g - purple line, Fig. 8d - green line. Fig. 8a and Fig. 8b illustrate respectively the cases of images interpolated and filtered by a Wiener filter.

The graphs in Fig. 9 show that the dependence of the standard deviation on the number of frames used is more pronounced than the dependence on the test image. This allows you to further consider analyzing the dependence of the standard deviation on the number of frames and the type of image, using graphical standard deviations averaged over the images.

Fig. 9 shows the deviations for various types of interpolations depending on the number of frames used. These graphs were obtained by averaging over the images presented in Fig. 2 and Fig. 8 and the corresponding normalization.

The graphs in **Fig. 10** allow us to conclude that if we average the mean distortion of the implementations of the shift matrix S_m and normalize it to the mean deviation value for one frame, then the dependence of the mean deviation from the type of image is significantly weakened. This makes it possible to predict the value of the normalized standard deviation, depending on the interpolation method and the number of frames used - Fig. 10.

(a)

(b)

Fig. 10. The RMS diagrams, averaged over 20 realizations of S_m and averaged over 5 images, are presented in Fig.2 and Fig.8. Graphs of the RMS of interpolated - (a) and filtered - (b) images depending on the number of frames used. The graphs correspond to: IWD - red line, cubic spline - green line, spectral interpolation - blue line, linear interpolation - black line.

5. CONCLUSION

Using multiple low-resolution frames to produce a high-resolution image requires several steps. The resulting low-resolution frames must be analyzed to determine the amount of displacement relative to each other. The results of solving this non-simple task significantly affect the final result. The second stage corresponds to obtaining a high-resolution image using interpolation based on the already calculated displacement values of low-resolution frames. With an increase in the number of source frames, the deviation decreases. However, the magnitude of the standard deviation depends on the type of interpolation used. Usually interpolation errors are considered when comparing with a test image. But comparison of the average image with the interpolated image does not give a complete picture (Fig. 7a). In our case, it is advisable to consider the standard deviation on the basis of a comparison of the filtered image with the original non-averaged image (Fig. 7b). Such a comparison

suggests that it is advisable to use cubic spline and spectral interpolation. In addition, it follows from Fig. 10 that spectral interpolation can have a certain advantage over interpolation by a cubic spline in the case of small amounts of low-resolution frames used.

The work was carried out within the framework of the state task

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