Research on Fast Estimation Method of Fuzzy Parameters for Motion Blurred Images

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Abstract. Motion blur distortion is the most common type of image distortion in daily life. The research on motion-blurred image restoration technology has developed more mature. Classical algorithms such as Wiener filter and Kalman filter and various improved algorithms can achieve better results, but they take a long time and have great limitations in actual image restoration application scenarios. To solve this problem, this paper proposes an algorithm for fast restoration of image motion blur, an improved algorithm based on Random transform to judge the image motion blur angle, and studies the algorithm for estimating the blur length under the condition that the blur angle is determined, and obtains two motion blur parameters of blurred image. Experimental results show that the fast image restoration method proposed in this paper has shorter time consumption, stronger anti-noise interference ability and better practicability.

1. Introduction
Motion blur distortion is the most common type of image distortion in life. The most important step in restoring motion blurred images is to find the fuzzy parameters of motion blurred images, and then restore the images according to the fuzzy parameters. In recent years, many methods have been applied in the field of motion blur parameter detection and image restoration, which can accurately identify the blur angle and blur scale. However, these methods focus on reducing the estimation error of fuzzy parameters, and pay little attention to the running time of the algorithm, so they can not realize the fast restoration of blurred images. In this paper, based on the method of Random transform on spectrum image, the calculation amount of the algorithm is reduced by setting the region of interest and adjusting the calculation step. Compared with the previous identification methods, this method has a greater reduction in calculation time and higher detection accuracy.

2. Motion blurred image model
A classic image degradation model is shown in Figure 1[1]. In which f(x, y), h(x, y), g(x, y) and n(x, y) are original image, Point Spread Function (PSF)[2], motion blurred image and additive white Gaussian noise respectively[3]. When the fuzzy system is a spatially linearly moving invariant system, the degradation model can be expressed by the following mathematical formula:

\[ g(x, y) = f(x, y)*h(x, y)*n(x, y) \] (1)

Where ** is a linear convolution operator.
If the motion blur direction is known, coordinate rotation transformation is performed on the motion blur image to make the blur direction horizontal. At this time, Equation (1) can be simplified as

\[ g(x) = f(x) * h(x) + n(x) \]  

(2)

It is assumed that the process of image degradation is not affected by defocus except relative motion. Image \( f(x, y) \) moves in a straight line at a constant speed along the \( x \) direction, and the motion blur scale is \( d \), then the point spread function \( h(x, y) \) can be approximately expressed as a window function, and the expression is as follows:

\[ h(x, y) = \begin{cases} 1/d & y = 0, 0 \leq x \leq d - 1 \\ 0 & \text{others} \end{cases} \]  

(3)

For the motion blur operators in other directions \([4, 5]\), the horizontal motion blur operators can be rotated by an angle of \((-90^\circ < \theta < 90^\circ)\) (counterclockwise is positive, clockwise is negative).

3. Parameter identification algorithm for typical motion blurred graphics

In a large number of researches on angle parameters of motion blurred images\([6, 7, 8]\), Fourier transform is a common method to study the characteristics of images in frequency domain.

The Fourier transform of formula (1) can obtain the frequency domain description in the process of image degradation, as shown in formula (4):

\[ G(u, v) = F(u, v)H(u, v) + N(u, v) \]  

(4)

\( G(u, v) \), \( F(u, v) \), \( h(u, v) \) and \( n(u, v) \) are Fourier transform of motion blurred image, motion blurred function, original image and noise respectively. Without considering noise, the process of image degradation can be shown as formula (5):

\[ G(u, v) = F(u, v)H(u, v) \]  

(5)

On this basis, assuming that the process of image degradation is uniform linear motion, the motion blurred image can be expressed as:

\[ g(x, y) = \int_{-\infty}^{\infty} f(x - x_0(t), y - y_0(t)) \, dt \]  

(6)

Fourier transform on the above formula can be obtained

\[ G(u, v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} g(x, y) e^{-j2\pi(ux_0+vy_0)} \, dx \, dy = F(u, v) \int_{0}^{T} e^{-j2\pi(ux_0(t)+vy_0(t))} \, dt \]  

(7)

\( x_0(t) \) and \( y_0(t) \) are the changes of the image in \( x \) and \( y \) directions in \( t \) time, and \( t \) is the image exposure time. According to formula (5) and formula (7):

\[ H(u, v) = \int_{0}^{T} e^{-j2\pi(ux_0(t)+vy_0(t))} \, dt \]  

(8)

If the distance of the image moving in \( X \) and \( Y \) directions in time \( t \) is \( A \) and \( B \) respectively, the above formula can be obtained:
Under the condition of image size $M \times N$, there are

$$H(u, v) = \frac{T \sin(\pi (ua + vb))}{\pi (ua + vb)} e^{-j\pi (ua + vb)}$$  \hspace{1cm} (9)

According to the functional properties of the above formula, $H(u, v)$ can reach the maximum value $T$ at $\frac{ua}{N} + \frac{vb}{M} = 0$, and $H(u, v) = 0$ when it is not 0. It can be seen that several dark stripes with equal spacing will appear on both sides of the image spectrum parallel to the bright stripes under the condition of uniform linear motion blur, and the inclination angle of the bright stripes is $\frac{ua}{N} + \frac{vb}{M} = 0$, that is,

$$\tan(\varphi) = \frac{a}{b} \cdot \frac{M}{N}$$  \hspace{1cm} (11)

If the motion blur angle of an image is defined as the included angle with the positive direction of the X axis, $\tan(\theta) = \frac{b}{a}$, and the motion blur angle can be known from the above formula:

$$\tan(\theta) = \tan(\varphi - \frac{\pi}{2}) \cdot \frac{M}{N}$$  \hspace{1cm} (12)

It can be seen from the above formula that the motion blur angle of the image can be calculated according to the spectrum fringe angle and the image size.

The estimation of fuzzy scale$^{[9]}$ is based on the known fuzzy angle, rotating the image to make the fuzzy direction horizontal, differentiating the rotated image to obtain a differential image, then calculating the autocorrelation of the differential image$^{[10]}$, and adding the autocorrelation results in each column to obtain the discrimination curve$^{[11]}$. A simple discrimination curve is shown in the following figure. The curve has the highest correlation degree at point 0, showing a zero-frequency peak, and the lowest correlation degree at the edge of image blur, showing a minimum value, which is distributed on both sides of the maximum value. The size of image blur scale is half of the distance between negative peaks.

4. Improved fast estimation algorithm of motion blurred graphics parameters

4.1 Fuzzy Angle Estimation

In this paper, the method based on Randon transform$^{[12]}$ is used to calculate the direction angle of
spectral fringes$^{[13]}$ of motion blurred images. Radon transform is to integrate the image along different straight lines, the distance between the straight line and the center of the image is $d$, and the direction angle is $\theta$. The specific calculation formula is as follows:

$$ R(G)(d, \theta) = \int_{-\infty}^{\infty} G(d \cos \theta - t \sin \theta, d \sin \theta + t \cos \theta) dt$$

(13)

Because there is a group of oblique bright stripes$^{[14]}$ in the image spectrogram, and the integral value along the oblique direction is the largest, the direction angle of motion blur can be known by finding the maximum value through Radon transform$^{[15]}$. Due to the large amount of computation of Radon transform, the computation speed is seriously affected. Considering that the blur degree of motion blurred images is basically the same at all positions, this paper adopts the method of keeping some images and reducing the area for computation, and optimizes the step length of tilt angle. Based on the least computation, the step length of calculating tilt angle is 10. The experimental results show that the program can greatly reduce the running time of the program, and there is no obvious difference in the accuracy of tilt angle calculation compared with the original method.

4.2 Fuzzy scale estimation

In this paper, the estimation of blur scale is based on the calculation of blur angle, and the spectrum image of motion blurred image is rotated by corresponding angle and binarized. Because when $\frac{ua + vb}{N + M}$ is not 0, $H(u,v)=0$, the spectrum image presents dark stripes, and the blur scale can be obtained according to the distance between dark stripes. The calculation formula is as follows:

$$ L = \frac{N}{d}$$

(14)

$L$ is the blur scale, $N$ is the image width, and $d$ is the distance between adjacent dark stripes. Because the distance between the dark stripes on both sides of the central bright stripe in the spectrum image is $2d$, this paper directly looks for the nearest dark stripe from the central position of the spectrum image, which only needs half of the calculation amount and reduces the calculation time.

5. Experimental results and analysis

In order to verify the efficiency and accuracy of the proposed method for parameter estimation of motion blurred images, some blurred images with blur scale of 10~50, blur direction of 0 ~ 180 and pixels of 658×411 are selected, and the experimental results of this paper are compared with those of the classical algorithm, as shown in the following table.

| Table 1 Fuzzy Angle Estimation Results |
|-----------------|-----------------|-----------------|-----------------|
| Fuzzy scale (pixel) | Fuzzy angle (°)   | Fuzzy angle estimated value/absolute error value/time consumption (s) | 
|                  |                  | Radon transformation method  | This method |
|---|---|---|---|
| 10 | 10 | 10/0/12.21 | 10/0/0.52 |
|   | 30 | 29/1/12.30 | 29/1/0.59 |
| 20 | 50 | 51/1/8.43 | 51/1/0.37 |
|   | 70 | 70/0/7.95 | 71/1/0.48 |
| 30 | 90 | 90/0/8.66 | 90/0/0.39 |
|   | 110 | 110/0/8.17 | 110/0/0.37 |
| 40 | 130 | 130/0/8.24 | 130/0/0.36 |
|   | 150 | 150/0/8.50 | 150/0/0.43 |
| 50 | 170 | 170/0/8.44 | 170/0/0.36 |
| Average error/average time consumption | 0.22/9.21 | 0.33/0.43 |
6. Conclusion

In this paper, the fuzzy parameters of motion blurred images are studied, and an improved fast estimation algorithm of fuzzy parameters is proposed. The experimental results show that the proposed method has greatly improved the calculation time compared with the traditional algorithm, and does not significantly reduce the accuracy of fuzzy parameter estimation. For example, the reduction of imaging quality caused by lens jitter in photographing scene can be significantly reduced. The further research direction can focus on reducing the amount of calculation of blur angle estimation, so as to improve the recovery speed of motion blurred image, and be applied to the recovery of high-resolution image and video.

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| Fuzzy scale (pixel) | Fuzzy angle (°) | Fuzzy scale estimation value/absolute error value/time consumption (s) |
|---------------------|----------------|------------------------------------------------------------------|
| 10                  | 10             | 9.13/0.87/0.11                                                    |
|                     | 30             | 13.93/3.93/0.15                                                   |
| 20                  | 50             | 18.27/1.73/0.15                                                   |
|                     | 70             | 17.49/2.51/0.14                                                   |
| 30                  | 90             | 28.34/1.66/0.10                                                   |
|                     | 110            | 29.36/0.64/0.15                                                   |
| 40                  | 130            | 37.36/2.64/0.10                                                   |
|                     | 150            | 37.36/2.64/0.10                                                   |
| 50                  | 170            | 32.88/17.12/0.09                                                  |
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