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Research Article
Identification of Motion Blur Direction Using Bresenham Algorithm for Straight Line

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Abstract

Relative movement between the objects and the camera may leads to the occurrence of motion blur. Restoration of the motion blurred image plays an important role in such areas as astronomy and military. The Point Spread Functions (PSF) of blurred images must be known in order that classic restoration algorithms can apply to image restoration. Since the point spread functions of the blurred images shaped during uniform linear motion is determined by the direction and the displacement of motion, this study proposes a method in combination with Bresenham algorithm for straight line to sum up the gray values of the spectrogram of blurred images via twice Fourier transform and to determine the direction of motion. The experiments demonstrate the algorithm proposed in this study can make relatively accurate judgment on the direction of motion of blurred images in a simple and fast way, especially with higher accuracy of judgment for 45°, 90° and more special angles. Moreover, the proposed algorithm can process blurred images with different height-width scales. Having the aid of the proposed algorithm, the restoration effect of the blurred image is satisfying.

Key words: Motion blur, image restoration, detection of motion direction, Bresenham algorithm, plot of frequency spectrum

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INTRODUCTION

During the processes of shooting, formation, transmission, storage, output and display of image, due to the flaws within the imaging system and the effects of the impurities existing in transmission media, relative motions and more factors, the image may go deteriorated, distorted and degenerated to different degrees. However, in astronomy, military affairs, transportation, medical science, industrial control and more areas where high-quality images are in need for use, very high requirement has been raised for image resolution. The principal goal of image restoration is to improve an image in some predefined sense[1].

There are a number of causes for image blur and deterioration in quality, the blur caused by relative movement between imaging equipment and the objects in the filming process is known as motion blur. Classic restoration algorithms such as Wiener filtering algorithm, regularized filtering algorithm and L-R algorithm can achieve better effect in restoring motion blurred images but all these algorithms demand sufficient knowledge about degeneration and point spread function[2] in order to restore blurred images. So, for blurred images obtained from actual shooting, the corresponding point spread functions must be determined before the restoration in order that the algorithms mentioned above can apply to image restoration.

Since velocity-variable nonlinear motion can be viewed as approximate uniform linear motion or decomposed into multiple uniform linear motions in the moment of imaging, the study on the blur of uniform linear motion is of generality and representativeness. The point spread function of the blurred images shaped during uniform linear motion is determined by the direction and the displacement of motion, thus the first step to restore images is to estimate the direction of motion and the exact distance the motion has covered.

Lokhande *et al*.[3] identifies the direction of motion using Hough transform based on the spectrum features of blur but if the blurring characteristic of image is indistinct, the effect of identifying direction of motion would be unsatisfactory by this method. Oliveira *et al*.[4] puts forward a modified method to judge the direction of motion against smaller blur distance but this method fails to relate to treatment of special angles such as 45°. Yitzhaky and Kopeika[5] and Yitzhaky *et al*.[6] employ 2×2 differential operator to recognize the direction of motion of blurred images but this method applies only to the range of 0~45° with larger error of estimation. Xie and Qin[7] proposes an approach to estimate the PSF parameter using the cepstrum analysis method, by this approach the error of estimation is smaller when the blurred length ranges from 5 pixels to 55 pixels but surges dramatically when the blurred length goes beyond this range. Liu[8] raises a method which applies Fourier Transform (FT) twice to the blurred images and detects the angle of inclination by applying a statistical method of gray values to the processed images so as to judge the direction of motion but fails to present any detailed algorithm to implement it; moreover, in the images through twice of FT as presented in the literature, the core part, the bright line mentioned with regard to this method is not clear, which brings about much difficulty to the counting of the gray values of image. Through analysis, Deng and Xiong[9] and Le *et al*.[10] hold that the trend of the dark stripes in the image's frequency spectrum and the direction of the motion blur are perpendicular to each other but this rule applies only on the occasion where the image's length and width are equal, while blurred images typically have a different length from width.

This study puts forward an algorithm that utilizes the Bresenham algorithm in computer graphics to sum up the gray values of a blurred image's plot of frequency spectrum so as to determine the direction of motion.

Principles of motion blur and characteristics of image spectrum: A digital image is composed of a finite number of pixels with different brightness. The degree of light and shade of all pixels in digital images is represented by the gray level. The motion blur of image is caused by the relative movement between imaging equipment and the objects during the time from opening to closing the shutter of the imaging device. Since, a digital image is made up of numerous pixels, image motion is actually the holistic motion of all the pixels constituting this frame of image. The motion-blurred image is actually the final image formed by the same scenery image through a series of range delay and superposition.

Motion blur degradation model: An image can be defined as a two-dimensional function f(x, y), where x and y are spatial coordinates and the value of f(x, y) represents the gray level of the image at any pixel point appointed by any pair of coordinates (x, y). In a linear, position-invariant motion blur system, f(x, y) is the original image, $x_0(t)$ and $y_0(t)$ are respectively the variables of motion on the x and y directions during t time, T refers to the time from opening to closing the shutter of the imaging device and n(x, y) is additive noise, thus the blurred image g(x, y) can be expressed as:

$$g(x, y) = \frac{1}{T}\int_0^T f\left[x - x_0(t),\ y - y_0(t)\right]dt + n(x, y) \qquad (1)$$

To simplify the problem, the effect of noise can be ignored and then Eq. 1 is simplified into Eq. 2:

$$g(x, y) = \frac{1}{T}\int_0^T f\left[x - x_0(t),\ y - y_0(t)\right]dt \tag{2}$$

Apply FT to Eq. 2 to get Eq. 3:

$$\begin{aligned} G(u, v) &= \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\left\{\frac{1}{T}\int_0^T f\left[x - x_0(t),\ y - y_0(t)\right]dt\right\} e^{-j2\pi(ux+vy)}dx\,dy \\ &= \frac{1}{T}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\left\{\int_0^T f\left[x - x_0(t),\ y - y_0(t)\right]dt\right\} e^{-j2\pi(ux+vy)}dx\,dy \end{aligned} \tag{3}$$

Exchange the order of the integration in Eq. 3 to get Eq. 4:

$$G(u, v) = \frac{1}{T}\int_0^T\left\{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f\left[x - x_0(t),\ y - y_0(t)\right] e^{-j2\pi(ux+vy)}dx\,dy\right\} dt \tag{4}$$

According to the displacement property of FT, Eq. 4 can be written as:

$$\begin{aligned} G(u, v) &= \frac{1}{T}\int_0^T F(u, v)\ e^{-j2\pi(ux_0(t)+vy_0(t))}\ dt \\ &= F(u, v)\frac{1}{T}\int_0^T e^{-j2\pi(ux_0(t)+vy_0(t))}\ dt \end{aligned} \tag{5}$$

Given:

$$H(u, v) = \frac{1}{T}\int_0^T e^{-j2\pi(ux_0(t)+vy_0(t))}\ dt$$

then Eq. 5 can be written as G(u, v) = H(u, v) F(u, v). Suppose the image covers a distance of L, the direction of motion stretching an angle of θ with respect to the horizontal direction, within the time period T from the opening to the closing of the imaging device's shutter, then given in Eq. 6:

$$H(u, v) = \frac{\sin(\pi(u\cos\theta + v\sin\theta)L)}{\pi(u\cos\theta + v\sin\theta)L}e^{-j\pi(u\cos\theta+v\sin\theta)L} \tag{6}$$

When the direction of motion θ = 0, u cos θ+v sin θ = u and Eq. 6 becomes simplified into:

$$H(u, v) = \frac{\sin(\pi uL)}{\pi uL}e^{-j\pi uL} \tag{7}$$

Observe the term sin (πuL)/(πuL) in Eq. 7 to find this is a function with a similar form to sin[c (x)]: When $x = n\pi$ (n = ±1, ±2, ±3,...), then sin[c (x)] = 0. Accordingly, when u = ±1/L, ±2/L, ±3/L,..., then $H(u, v) = 0$. The spectral amplitude of H(u, v) is:

$$|H(u, v)| = \left|\frac{\sin(\pi uL)}{\pi uL}e^{-j\pi uL}\right|$$

The zeros of H(u, v) are manifested as dark stripes in its plot of frequency spectrum, whereas the peaks as bright ones. Hereby, it can be speculated that there exist a series of alternately bright and dark parallel stripes in the spectrogram of H(u, v). According to Eq. 5, when the value of H(u, v) is zero, accordingly the value of G(u, v) is also zero. Since $|G(u, v)| = |H(u, v)\,F(u, v)| = |H(u, v)||F(u, v)|$, there also exist a series of parallel bright-and-dark stripes in correspondence to H(u, v) in the spectrogram of the blurred image g(x, y).

Analysis of plot of frequency spectrum: Apply FT to the blurred image g (Fig. 1a) and determine its plot of frequency spectrum and the result is shown as Fig. 1b. It can be noticed that the alternately bright and dark parallel stripes do exist in the plot of frequency spectrum of the blurred image but the rule of the trend of the stripes is indistinct for observation and research. To simplify the visual analysis into the frequency spectrum, the origin of transform is moved from the position at the top left corner of the image to the central position inside the frequency rectangle. The result is shown as Fig. 1c, from which it can be observed that the trend of the bright-and-dark stripes is even distinct with rules to follow. By making a comparative analysis between the plots of frequency spectrum of different motion directions, it is discovered that the trend of the stripes in the plots of frequency spectrum is always perpendicular to the directions of motion of the blurred image. Because motion blur has reduced the high-frequency components of the image along the direction of motion, the high-frequency components of the image along other directions are less affected and the more they deflect from the direction the less they are affected.

Apply FT again to Fig. 1c and determine the plot of frequency spectrum G' and the result is shown as Fig. 2.

In Fig. 2 there appears a distinct high bright straight line along the direction of motion. If only the angle (in degrees) between this bright line and the horizontal direction is figured out, the image's direction of motion can be determined. The method of summation of gray values can be adopted to detect the angle (in degrees) between the bright line in G' and the horizontal direction. The bright line with the maximum gray value marks the motion direction of the blurred image.

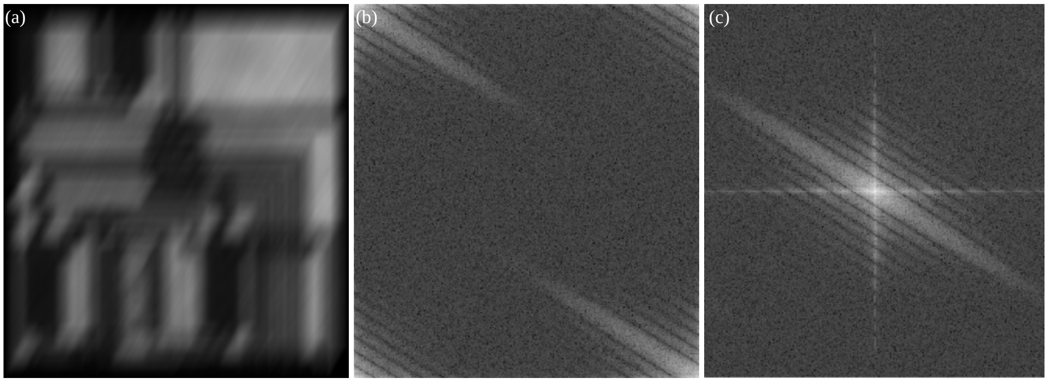

Fig. 1(a-c): (a) Blurred image when L = 30 and θ = 60, (b) Plot of frequency spectrum after applying Fourier transform to part a and (c) Moving the origin of transform of part b to the center of frequency rectangle

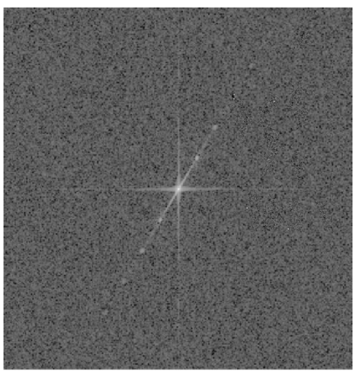

Fig. 2: Plot of frequency spectrum G' via the second Fourier transform

With the central point of the image G' as the endpoint of the straight line to be detected and the origin of rectangular coordinate plane, compute the gray value of the straight line in correspondence to each angle within a range of 0~180° and the straight line with the maximum gray value is a bright line, to which the corresponding angle indicates the direction of motion.

Bresenham line-generating algorithm: The gray value of a straight line to compute is actually to sum up the gray values of all points in that line. To fast determine which pixels are positioned in a same straight line, the Bresenham algorithm for straight line[11,12] in computer graphics can be employed. This algorithm is named after J.E. Bresenham who proposed it, used to fast generate a straight line. Since, a straight line is shown in the graphic display device, the coordinate values of all points in the straight line shall be figured out and each point is displayed in accordance to the coordinates. But because the coordinate system adopted in the display device is an integer coordinate system, while the coordinate values of all points in the straight line are real numbers, the points in the straight line are not necessarily exactly positioned at the pixels on the display device, which requires selecting the pixels that are closest to the straight line for display.

Two points determine a straight line. To generate a straight line on the display device, both endpoints, A(x_a, y_a) and B(x_b, y_b), of the line must be known. Assume x_B equaling x_A and y_B equaling y_A are incompatible. Next determine the coordinates of all points in the straight line between A and B. Use Bresenham algorithm to determine the coordinates of all points in the straight line AB, namely the steps to show the points in the straight line AB onto the graphic display are as the following (It is noticeable that expression "x = y" means the value of x is given by y):

- Compute the difference between the coordinates of points A and B as: $\Delta x = x_B - x_A$ and $\Delta y = y_B - y_A$. Take the respective absolute value of Δx and Δy to get: $\Delta x' = |\Delta x|$ and $\Delta y' = |\Delta y|$. Compare the magnitudes of Δx' and Δy'. If $\Delta x' \geq y'$, execute step 2, otherwise execute step 3
- If $\Delta x<0$, then exchange the coordinate values of endpoint A and those of endpoint B. Compute the difference between the coordinates of points A and B according to their new values. If $\Delta x \geq 0$, then the coordinate values of A and B remain unchanged. Make use of x and y to record the signs of Δx and Δy, respectively. The value of Δx certainly is larger than or equal to 0, so sx = 1, If $\Delta y \geq 0$, then sy = 1, else if $\Delta y<0$, then sy = -1

Compute the initial value of the deviation discriminant as $d = 2\Delta y' - \Delta x'$. Determine the endpoint A of the straight line as the point being processed for the moment. Given

$x = x_A$ and $y = y_A$. Suppose the initial value of the cycle index i is 0, repeat the following steps until $i>\Delta x'$:

- Display the current points according to the values of x and y
- Compute and update the values of x, y and d, respectively. If $d\geq 0$, then $x = x+sx$, $y = y+sy$ and $d = d-2(\Delta x'-\Delta y')$; otherwise, $x = x+sx$, $d = d+2\Delta y'$ and the value of y remains unchanged
- Increment the cycle index i by 1

◦ If $\Delta y<0$, then exchange the coordinate values of endpoint A and those of endpoint B. Compute the difference between the coordinates of points A and B according to their new values. If $\Delta y\geq 0$, then the coordinate values of A and B remain unchanged. Make use of x and y to record the signs of Δx and Δy respectively. The value of Δy certainly is larger than or equal to 0, so $sy = 1$; If $\Delta x\geq 0$, then $sx = 1$; else if $\Delta x<0$, then $sx = -1$

Compute the initial value of the deviation discriminant as $d = 2\Delta x'-\Delta y'$. Determine the endpoint A of the straight line as the point being processed for the moment. Given $x = x_A$ and $y = y_A$. Suppose the initial value of the cycle index i is 0, repeat the following steps until $i>\Delta y'$:

- Display the current points according to the values of x and y
- Compute and update the values of x, y and d, respectively. If $d\geq 0$, then $x = x+sx$, $y = y+sy$ and $d = d-2(\Delta y'-\Delta x')$; otherwise, $y = y+sy$, $d = d+2\Delta x'$ and the value of x remains unchanged
- Increment the cycle index i by 1

Bresenham algorithm for straight line is a recursive algorithm which enables speculation of the coordinate of the next point by that of the known point. In each step of speculation, floating-point arithmetic and rounding calculation are unnecessary with respect to the values of point coordinates x and y. The program compiled by the algorithm runs fast with advantages for being implemented on hardware.

Proposal of algorithm: Based on the above analysis, this study proposes a new algorithm to judge the direction of motion of blurred images:

- Apply FT and log transformation to a blurred image g and plot of frequency spectrum G is obtained

Apply FT to g to generate the plot of frequency spectrum G. Implement log transformation to compress the dynamic range of G with large variations in pixel values, so that a significant degree of intensity detail can be retained:

◦ Apply FT again to G, moving the origin to transform to the center of the frequency rectangle to determine the plot of frequency spectrum G' and implement log transformation again to G'

◦ Remove the brightness in G' generated in both horizontal and vertical directions

In the plot of frequency spectrum G', aside from the direction of motion where bright lines have existed, they may also appear in both horizontal and vertical directions as a possible result of mutation of gray scale on the image's edge[13]. Remove these bright lines caused by mutation of gray scale on the image's edge to detect the direction of motion with more accuracy:

◦ Figure out the angle between the bright line and the horizontal direction

By the property that the bright line crosses the central point of the image G' about which it is symmetric, the problem can be simplified into the mere detection of the angle (in degrees) between the bright line located in the upper area of G' and the horizontal direction, so that the amount of computation can be reduced from the algorithm.

With the central point of G' as the origin of rectangular coordinate plane and one of the endpoints of straight line, compute the tangent value of each angle within the range of 0~180° with 1° as the increment unit to get the slope of the straight line in correspondence to each angle. According to the slope obtained, use Bresenham algorithm to fast determine the pixels in each straight line and take the sum of the gray values of the pixels in a same straight line. The angle in correspondence to the straight line with the maximum sum of gray values is marked as θ, which is just the image's direction of motion.

In estimating the direction of motion, if higher demand is placed on the accuracy of detection, more accurate detection can be conducted within a partial sphere with 0.1° as a further increment unit after the general direction is determined.

RESULTS

The MATLAB is used as the experimental tool and the effect of the image's motion blur is simulated. When the

Table 1: Comparison of the estimated result of the proposed algorithm and those of Radon transform

Real angle (degree)	Angle estimated by the proposed algorithm (degree)	Error of the proposed algorithm (degree)	Angle estimated by radon transform (degree)	Error of radon transform (degree)
4	4	0	0	-4
12	12	0	0	-12
21	21	0	22	1
30	30	0	31	1
45	45	0	45	0
60	60	0	58	-2
76	76	0	90	14
90	90	0	90	0
100	99	-1	90	-10
120	119	-1	122	2
135	134	-1	135	0
146	146	0	145	-1
150	150	0	150	0
162	162	0	161	-1
175	175	0	180	5
180	180	0	180	0

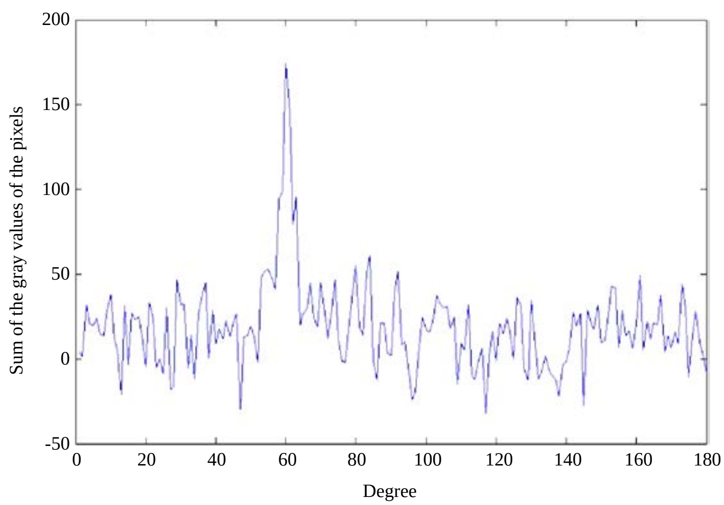

Fig. 3: Result of summation of gray values in G'

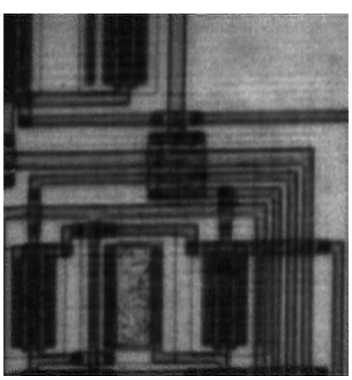

Fig. 4: Restored image

image's direction of motion is 60°, use the algorithm proposed in this study to detect the plot of frequency spectrum via twice TF to get the data as shown in Fig. 3.

Radon transform also can be used to judge the motion direction of blurred image. The comparison of the experimental results of the proposed algorithm in this study and those of radon transform are shown in Table 1, in which the error = estimated angle-real angle.

After getting the motion direction, estimate the motion distance of the blurred image[14,3] and making use of Wiener filtering algorithm restore the blurred image. The restoration result of Fig. 1a is shown in Fig. 4. Having the aid of the algorithm proposed in this study, the restoration effect of the blurred image is satisfying.

DISCUSSION

The experimental data demonstrate the proposed algorithm can make relatively accurate judgment on the direction of motion of blurred images, with the absolute value of error between the estimated direction and the real direction not exceeding 1°. From Table 1, the estimate accuracy of the proposed algorithm in this study is superior to that of radon transform[15]. The proposed algorithm has less complicated structure and smaller calculating quantity. Compared to the modified method[4], the proposed algorithm of this study has higher accuracy of judgment for special angles such as 45° and 90°. The proposed algorithm that can process blurred image with different height-width scales works out a solution to the rule mentioned[9].

Figure 2 indicates the bright lines in G' signifying the direction of motion are symmetric about the central point of the image. The experiment also evinces that if the image moves equal distances along the θ direction and the θ' = 180°+θ direction, respectively, then the plots of frequency spectrum of both via twice FT are almost identical. In using θ to restore the image whose actual direction of motion is θ', the amplitude of the restored image that results remains unchanged but all pixels in the image have made a displacement. Therefore distinct restored image can be obtained by using θ to restore the blurred image whose actual direction of motion is θ'.

CONCLUSION

Estimating the direction of motion of blurred images is an important step to restoring images. This study mainly probes into the problem of estimation of direction parameters of blurred images in uniform linear motion, raising a method in combination with Bresenham algorithm for straight line to sum up the gray values of the spectrogram of blurred images via twice FT and to determine the direction of motion. The aim of applying Bresenham algorithm is to fast compute the sum of gray values of each straight line.

Verified by a vast number of simulation experiments, the algorithm proposed in this study can make relatively accurate judgment on the direction of motion of blurred images under a condition without noise interference, especially with higher accuracy of judgment for 45°, 90° and more special angles. Moreover, without the demand that the target image to detect have equal width and height, the algorithm can process blurred images with different height-width scales.

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