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Electronic Image Stabilization of Phage Plaque Based on Full-Search Block-Matching Algorithm

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The phage plaque counting method is commonly used in theoretical research and microbiological applications. The number of plaques is calculated by acquiring the image of the plaque. However, the electronic image of the plaque can be affected by camera movement, thereby decreasing the stability of the image and making it difficult to determine the number of plaques. In order to address this problem, the electronic image of bacteriophage plaque is preprocessed using the fast-matching, full-search algorithm. Starting with the fast-matching, full-search estimation model of a bacteriophage electronic plaque image, the whole search block-matching algorithm is applied to stabilize the bacteriophage plaque. In the stabilization process, the full-search block-matching algorithm is used for the operation in parallel. The matching improves the computational speed of the full-search block-matching algorithm, and reduces the effect of camera movement by stabilizing the electronic plaque image. Experiments show that the motion trajectory of the electronic image of bacteriophage plaque becomes more stable aft er the stabilization effect of the algorithm. The difference between two frames of the bacteriophage plaque image is reduced, the image resolution is improved, and a well-stabilized electronic image of the bacteriophage plaque is obtained.

Keywords: full-search block-matching, phage plaque, electronic image, stability, parallel computing, motion compensation

1. INTRODUCTION

Phages are the focus of research and application in the life sciences and medicine domains, and in the fermentation industry. Basic microbiological data comprises a number of phages. By calculating this number, the number of viruses and phage titer can be obtained (Jia and Yang, 2017; Zhang and Ma, 2015). At present, the counting method used on plaque is usually manual, with inconsistent results, mainly because the camera movement leads to poor image stability of the electronic plaque image (Ridzuan et al., 2019; Zhu et al., 2018). Therefore, finding effective methods to improve the stability of electronic plaque images has important practical value. A great deal of research has been conducted on electronic image stabilization algorithms. The most common methods include: grayscale projection, representative point matching, and feature matching, to name a few. However, all these algorithms have poor noise resistance and low parallel-operation efficiency. The stable state of the electronic plaque image depends mainly on the position of the camera. The motion trajectory of the electronic plaque image should be estimated, and the motion compensation of the electronic plaque image through the motion trajectory is the key to stabilizing the image (Jiao et al., 2018; Li and Liu, 2016; Li and Zhang, 2016). In order to stabilize the electronic

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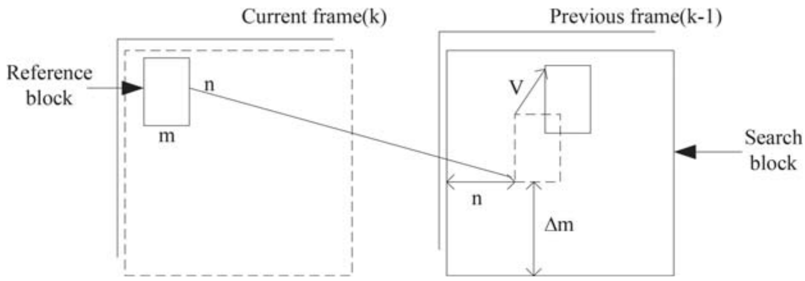

Figure 1 The flow chart of matching full-search block.

image of plaque, the position vector of the global motion of the image of plaque should be obtained first, and then the current frame should be compensated. Therefore, an electronic image stabilization algorithm for plaque based on full-search block-matching was applied and studied in this paper. With this algorithm, the defects of high complexity and computational redundancy are addressed, the position vector of the electronic plaque image is obtained, and the camera movement affecting the image quality is compensated to stabilize the image (Li et al., 2017).

2. ELECTRONIC IMAGE STABILIZATION ALGORITHM OF PLAQUE

2.1 Electronic Image Preprocessing of Plaque

The plates containing plaque were prepared using soft AGAR and two different plates were selected from among several plates. One plate contained a single plaque, the other contained two or two adjacent plaques. The electronic plaque image on the plate was obtained by the camera. Since the motion of the camera is circular, this causes the electronic plaque image to change. Therefore, in order to stabilize the image, it is necessary to establish a model to estimate and compensate for the circular motion ofthe camera (Gong et al., 2017; Xiao et al., 2016; Che et al., 2016).

2.2 A Motion Estimation Method for Full-Search Block-Matching

2.2.1 The Full-Search Block-Matching Estimation Model

Different motion complexity leads to the diversity of motion models describing two-dimensional objects. The proposed algorithm starts by establishing the affine motion model of the electronic plaque image, and then adopts the whole search block-matching algorithm to stabilize the image. The affine motion model can represent a series of motions of the electronic plaque image, including translation, rotation and scaling. These motions are a linear transformation (Bai et al., 2016), so the affine motion model of the image can be expressed by Equation (1):

$$\begin{matrix} x_0 \\ y_0 \end{matrix} = \begin{matrix} a_1 b_1 x_1 \\ a_2 b_2 y_1 \end{matrix} + \begin{matrix} c_1 \\ c_2 \end{matrix} \tag{1}$$

where, the pixel site-mark in the reference electronic plaque image and the real-time electronic plaque image is represented as (x_0, y_0), and the translational motion is represented as (x_1, y_1). The scaling and rotation transformation of the electronic plaque image is expressed as (a_1, a_2, b_1, b_2): In order to improve the efficiency of the proposed algorithm, the affine transformation process needs to be simplified. Namely, the translational transformation model ofthe electron image of plaque (Hao et al., 2016), and $V = (c_1, c_2)^T$ is used to describe the position vector. Then, the new affine motion model of the phagocytic electronic image, namely the phagocytic electronic image full-search block-matching estimation model, is shown in Equation (2):

$$\begin{matrix} x_0 \\ y_0 \end{matrix} = \begin{matrix} x_1 \\ y_1 \end{matrix} = + \begin{matrix} c_1 \\ c_2 \end{matrix} \tag{2}$$

2.2.2 The Principle of Full-Search Block-Matching Algorithm

The full-search block-matching algorithm is based on the estimation model of the electronic plaque image to determine the translational motion of the image on a two-dimensional plane. The overall flow ofthe full-search block-matching algorithm is shown in Figure 1.

Firstly, the whole-search block-matching algorithm is used to divide each frame of the electronic plaque image, with a size of $a \times b$. Put the sub-block of $a \times b$ into the current frame, take the position of a sub-block as the center position; similarly, take the position of a sub-block in the previous frame $(k-1)$ as the center position, and position the $(\Delta m + m) \times (\Delta n \times n)$ search window in the center of the previous frame. The matching block is found among all candidates in the whole-search window, that is, the block that is most similar to the current reference block under a certain matching criterion, and the relative displacement between the reference block and the matching block is described by the position vector V of the block. The full-search block-matching algorithm is a highly accurate motion algorithm, which is calculated based on the minimum absolute value error (Hwang et al., 2016). The absolute error formula is as follows.

$$MSE = \sum_{i=1}^{N} \sum_{j=1}^{N} |I_t(i, j) \cdot I_{t-1}(i + \theta_x, j + \theta_y) \tag{3}$$

where, θ_x and θ_y represents the error of the reference block at the candidate positions of x and y.

The steps are: firstly, ascertain the size and search range of reference blocks of the electronic plaque image. In the search window of similar blocks, apply the absolute error criterion. applied. Calculate the absolute error sum of the reference block at each candidate position, define the sum as θ, select the block with the minimum value of θ, treat it as a matching block, and obtain the relative displacement vector through the determination of matching block (Lu et al., 2015; Md Yatim et al., 2019). MSE represents the absolute error value of pixel values of two frames of electronic plaque images. The larger the MSE, the closer are the two frames of the electronic plaque image. PSNR value is used to evaluate the accuracy of the algorithm. The calculation formula of PSNR is as follows:

$$PSNR(I_1, I_0) = 10 \log [255^2 / MSE(I_1, I_0)] \tag{4}$$

where I_1 and I_0 represent the pixel values respectively of two adjacent frames in the electronic plaque image.

When the PSNR reaches its maximum value, the two frames of electronic plaque images coincide completely. The mean and variance of the pixel values of the two frames are obtained by means of the track average method, and the deviation degree of the electronic image's motion trajectory was tested with the mean, and the stability of the electronic image's motion trajectory was tested by the variance. The smaller the variance value, the better is the stability of the electronic image (Tan and Zhao, 2020). The smaller the mean value, the lower is the deviation degree of the motion trajectory of the electronic image, and the more stable is the image. The formulas for calculating the mean (5) and variance (6) are:

$$E = \frac{1}{N} \sum_{n=0}^{N-1} x_n - x_{n-1} \tag{5}$$

$$\sigma^2 = \sum_{n=0}^{N-1} (E - x_n)^2 \tag{6}$$

When the whole search block-matching algorithm is adopted, some matching blocks have a large offset position, which requires a large amount of relative displacement calculation. In order to reduce the complexity of the whole-search block-matching algorithm, the algorithm is implemented in parallel, and its accuracy does not change even though the algorithm is less complex.

2.2.3 The Parallel Algorithm of Full-Search Block-Matching

The parallel algorithm of full-search block-matching is used to process the computation process of full-search block-matching in parallel.

According to the absolute error formula above, the digital gradient of measure matching function is calculated as follows:

$$F(x, y) = grad[MSE(x, y)] \tag{7}$$

Since the formula (Equation (7)) for deriving the absolute displacement vector of the matching block is relatively complex, it is necessary to use the Taylor series approximation:

$$MSE(x, y) = MSE(x_0, y_0) + \Delta D gard[MSE(x, y)] \tag{8}$$

Here,

$$\begin{aligned} \Delta D &= \Delta x + \Delta y \\ \Delta x &= x - x_0 \\ \Delta y &= y - y_0 \end{aligned} \tag{9}$$

The minimum of the absolute error function is obtained with $MSE\ (x, y) = 0$. There is:

$$MSE(x, y) = MSE(x, y) + \Delta D gard[MSE(x, y)] = 0 \tag{10}$$

Displacement ΔD of matching block can be obtained after arrangement:

$$\Delta D = -\frac{MSE(x_0, y_0)}{grad[MSE(x_0, y_0)]} \tag{11}$$

The recursive model of displacement vector of matching block is obtained with:

$$D_{n+1} = D_n + \Delta D_n \tag{12}$$

According to Equation (12), the parallel algorithm is started, and C1 and C2 are used to track the extreme value points of the absolute error function in parallel. C1 and C2 represent pixel measure matching with the center pixel point in parallel, and the relative gradient is zero respectively. The parallel process is as follows: First, assume that the area of the fr ont array's electronic plaque image is $A \times B$ and the central pixel is $(0, 0)$, and use the symbol I to represent the current frame. There are four points parallel to I, which are expressed as $I\left(\frac{W_s}{2}, 0\right)$, $I\left(-\frac{W_s}{2}, 0\right)$, $I\left(0, \frac{W_y}{2}\right)$, $I\left(0, -\frac{W_y}{2}\right)$. The four points relative to I are denoted as $I\left(-\frac{W_s}{2}, \frac{W_y}{2}\right)$, $I\left(\frac{W_s}{2}, \frac{W_y}{2}\right)$, $I\left(\frac{W_s}{2}, -\frac{W_y}{2}\right)$, $I\left(-\frac{W_s}{2}, -\frac{W_y}{2}\right)$.

Calculate the digital gradient of the current frame I and other pixel point measure matching function. Find the pixel points with a digital gradient of 0, where the image gray level is represented as I(X, Y), the maximum parallel displacement is allowed to be represented as W_s, and the maximum vertical displacement is allowed to be represented as W_y. When conducting parallel computation, the minimum extremum of the measure-matching function is selected. This extreme point is the minimum out-of-frame direction of the electronic plaque image. Aft er finding the minimum frame loss direction, the search field is reduced by half and the calculation is resumed until the minimum frame loss direction is found again. The pixel points searched in the final minimum frame loss direction are taken as the center points, and then 9 new pixel points are searched to find the value of the minimum measure matching function of the $3*3$ square matrix. Then, the minimum measure matching function is used to calculate the position vector of the electronic image of plaque.

Through the above parallel computation, the position vector of the electronic plaque image can be calculated efficiently, so as to reduce the running time of the full-search block-matching algorithm and reduce the complexity of the algorithm. Furthermore, the stability degree ofthe electronic plaque image is judged according to the absolute error ofthe position vector. When the electronic plaque image is unstable, the movement trajectory ofthe electronic plaque image is compensated (Zhu et al., 2015; Li and Gao, 2018).

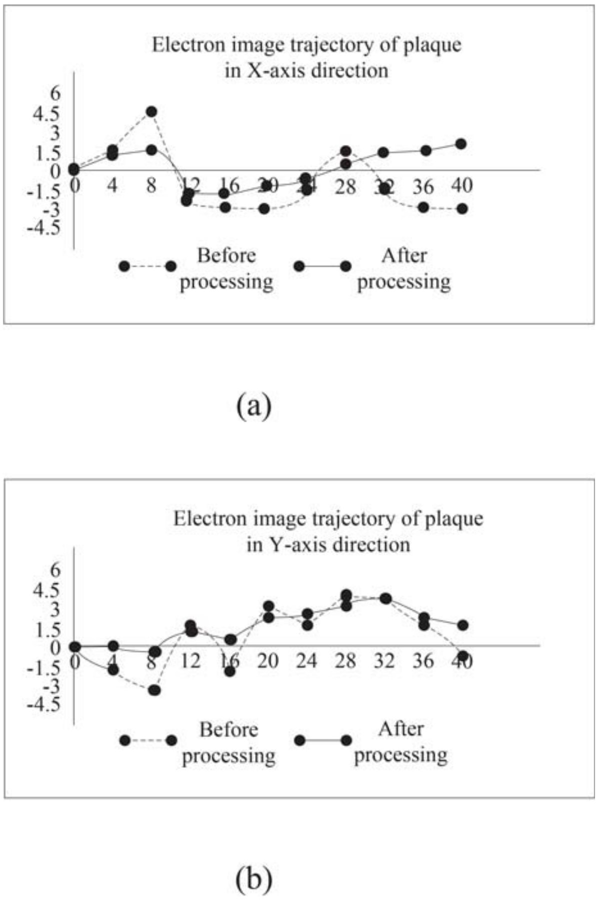

Figure 2 Different coaxial images of plaque trajectories.

2.2.4 The Motion Compensation

Motion compensation is based mainly on the movement of pixels to reduce or eliminate the jitter of the electronic image of plaque (Kumar and Baskaran, 2011). Through the estimation of image motion, several inter-frame position vectors are obtained, which are the moving pixel data. Therefore, in order to make the image more stable, further processing of electronic plaque image is needed. The average trajectory method was used to obtain the motion parameters of the two frames of electronic plaque images before and after processing, and the motion parameters obtained were as follows:

$$\Delta x_i = \frac{x_{i-2} + x_{i-1} + x_i + x_{i+1} + x_{i+2}}{5} - x_i$$
$$\Delta y = \frac{y_{i-2} + y_{i-1} + y_i + y_{i+1} + y_{i+2}}{5} - y_i \tag{13}$$

According to the absolute error calculated by Equation (3), if the absolute value and minimum of elements in the expected matrix are 1, two best matching matrices should be selected. The sum of the obtained minimum element values is stored in the new matrix, and the original matrix corresponding to the minimum value is the best matching block of the comparison block in the search block.

The relative position vector median represents the vast majority of position vectors. Therefore, the median value of all relative displacement vectors is selected to calculate the actual relative displacement vectors of two adjacent frames, and the position vectors that need to be compensated for the subsequent frames are obtained. For motion compensation, the absolute position vector, namely the absolute position of frame i, is expressed as x_i. Because the relative position vector is used for the calculation, the difference between the position vector of the last frame and the current frame is $(x_i - x_{i-1})$ or $(y_i - y_{i-1})$. Equation (13) needs to be reformed, and the formula can be integrated, split and eliminated to obtain: Since the relative displacement vector is subtracted fr om the previous term by the latter term, the value obtained may be negative. Therefore, the negative sign should be extracted to obtain a new motion parameter formula: The motion parameters stated in Equation (15) were used to compensate the inter-frame position vector of the electronic image of plaque, in order to improve the stability of the electronic image of plaque.

3. EXPERIMENTAL ANALYSIS

3.1 The Experimental Conditions

In the experiment, an electronic plaque image obtained by simulating camera shake was obtained by Optibase image acquisition software. The image is a full-color AVI image with a size of 320×240 and a size of17.45 MB. The sampling frame speed is 32 frames/s, and the actual playback speed is 30.1 fr ames/s. The sampling time of the electronic plaque image is 2.5 s. A total of 85 frames of images were included. The

$$\Delta x_i = \frac{(x_{i-2} - x_{i-1}) + (x_{i-1} - x_i) + (x_{i-1} - x_i) + (x_{i+1} - x_i) + (x_{i+1} - x_i) + (x_{i+2} \cdot - x_{i-1})}{5}$$
$$\Delta y = \frac{(y_{i-2} - y_{i-1}) + (y_{i-1} - y_i) + (y_{i-1} - y_i) + (y_{i+1} - y_i) + (y_{i+1} - y_i) + (y_{i+2} \cdot y_{i-1})}{5} \tag{14}$$

$$\Delta x_i = \frac{-(x_i - x_{i-2}) - 2(x_i - x_{i-1}) + (x_{i-1} - x_i) + (x_{i+2} - x_i)}{5}$$
$$\Delta y = \frac{-(y_i - y_{i-2}) - 2(y_i - y_{y-1}) + 2(y_{i=1} - y_i) + (y_{i+2} - y_i)}{5} \tag{15}$$

simulation test of pixel motion estimation and compensation of electronic plaque image was carried out by MATLAB.

3.2 Test of Image Motion Trajectory

For the experimental, 85 frames of electronic plaque images were selected to detect the their planar motion trajectories before and aft er the application of this algorithm, as shown in Figure 2. It can be seen that the motion trajectories of the electronic plaque image in the X-axis and y-axis directions processed by the proposed algorithm are more subtle and the amount of fluctuation is greatly reduced, indicating that the algorithm effectively solves the jitter problem of the electronic plaque image.

Within the search range of different horizontal planes, the proposed algorithm obtained the mean value and variance parameters of pixel values of two frames of electronic plaque images on the X axis and Y axis before and after processing, as shown in Table 1.

The data in Table 1 show that the mean value and variance of the pixel values of the two frames of electronic plaque images on the X-axis are decreased after the application of the proposed algorithm. The data indicates that the X axis of electronic plaque image sequence frame deviates less from the image and deviates from the optical axis, and the pixel trajectory becomes more stable. Similarly, the motion trajectory of the y-axis also becomes more stable, indicating that the proposed algorithm can reduce the effect of camera movement on the electronic image sequence of the plaque.

3.3 Image Stability Test

With this method, there are many random factors that can affect the electronic plaque image. These can be environmental factors and sensor types, various features of the image, and the motion rules of the sequence of the image. In order to determine the effect of stabilization on the electronic plaque image, the quality of the image must be evaluated. The electronic plaque image processed with the stabilization algorithm is compared with the electronic plaque image after stabilization with the algorithm. The difference is demonstrated by Figure 3 below.

Figure 3(a) depicts the difference between the current image frame and the reference image frame before stabilizing the electronic plaque image. Figure 3(b) shows the difference between the compensated image frame and the reference image frame aft er image stabilization. The difference before and aft er image stabilization of electronic plaque image was compared. When the pixel value of the images was zero, the position vector between the two images was fully compensated. At this time, the image is shown in black. The closer the two images, the smaller is the difference, and the more stable is the image sequence. It can be seen from Figure 3 that the difference between the two images of plaque aft er the stabilization treatment with the algorithm in this paper decreases, and the image is more stable than prior to stabilization, which greatly reduces the instability of the sequence of the electronic plaque image and stabilizes it.

3.4 Algorithm Accuracy Test

After camera shake, the stability of the electronic plaque image can be judged according to the resolution of the algorithm. The change degree of PSNR reactive electronic plaque image sequence was used to evaluate the stability accuracy of the algorithm. MSE represents the absolute error value of pixel values of two frames of electronic plaque images. The larger the MSE is, the closer the two frames of electronic plaque images are. When PSNR reaches its maximum value, the two frames of electronic plaque images completely coincide.

In this paper, the algorithm can identify the minimum value of the motion variation of the electronic plaque image, which represents the algorithm resolution, and determines the accuracy of the algorithm according to its resolution. Assuming that $1/x$ describes the minimum displacement between two adjacent images, the PSNR is the largest, indicating a better stabilization of the image. The original PSNR was obtained by artificially synthesizing two frames of electronic plaque images and comparing the displacement between the two frames of electronic plaque images. The original PNSR was taken as the lower limit and the algorithm was used to stabilize the electronic plaque image. If the displacement of two frames of electronic plaque images is large, the PSNR after stabilization will be much higher than the lower limit. The level of displacement is decreased and the above process is repeated. When the stable PSNR and the lower limit are almost the same, the calculation is terminated; the resulting displacement is the algorithm resolution. In the experiment, PSNRO was taken as the PSNR value of the electronic image of protophage, and PSNRI and PSNR2 were defined as the stability algorithm for the PSNR value before and aft er stabilization. The matching resolution of the stability algorithm in this paper was obtained by calculation, as shown in Table 2.

Table 1 Comparison of parameters before and aft er processing.

		Before Processing	After Processing
	E	0.413	0.314
X-axis	σ^2	2.987	1.358
	E	−0.342	−0.375
y-axis	σ^2	4.889	1.735

(a) Electronic image showing difference between two plaque frames after stabilization

(b) Electronic image showing difference between two plaque frames after stabilization

Figure 3 Electronic images showing difference in electronic plaque images before and aft er stabilization.

Table 2 Values showing that the stability algorithm matches the statistical results of resolution.

Displacement	PSNR0	PSNR1	PSNR2	Changes (%)
1	32.2856	21.1231	51.7951	Increase 60.42
1/2	37.5983	44.8542	44.6589	Increase 18.77
1/3	39.4978	39.9836	44.0135	Increase 11.43
1/4	42.5632	42.5632	45.1268	Increase 6.23
1/5	43.4612	43.4612	44.5326	Increase 2.65
1/6	44.5632	44.5632	45.6142	Increase 2.36
1/7	47.5896	47.5896	48.6106	Increase2.15
1/8	47.8641	47.8641	48.8869	Increase2.13

As can be seen from Table 2, the displacement is inversely proportional to the original PSNR value of the electronic plaque image. That is, the smaller the displacement, the larger the original PSNR value. Moreover, when the displacement is greater than $1/2$ pixel, PSNR1 changes greatly compared with PSNR0. When the displacement is greater than or equal to $1/4$ pixel, the original PSNR value is equal to the PSNR value before the parallel full-search block-matching algorithm is applied. This means that the discrepancy between two frames of electronic plaque images cannot be identified before the stabilization process is carried out by the proposed algorithm. The PSNR value of the electronic plaque image was still changed after the stabilization treatment using the algorithm, and the gap between the PSNR value and the original PSNR value was gradually narrowed. When the pixel is 1/6, there is no significant change. It is found that the image resolution of the electronic plaque image is significantly improved and a better stabilization effect is achieved by the proposed algorithm.

4. CONCLUSIONS

In this paper, the stability algorithm based on full-search block-matching is applied to the electronic plaque image and studied in depth. It was found that the algorithm solves the problem of camera movement by reducing its effect, thereby improving the stability of the electronic plaque image. The main advantages of this algorithm are:

(1) When applying the full-search block-matching algorithm to improve the stability of the electronic plaque image, the variance in the moving track of the image is checked for stability. The mean value is used to check the degree of deviation of the moving track, which greatly improves the electronic plaque image.

(2) The whole search block-matching parallel operation was adopted to calculate the whole search block-matching simultaneously, so as to improve the operating speed of the algorithm and improve the electronic plaque image.

(3) The trajectory average was used to obtain the motion parameters of the two frames of the electronic plaque image before and after processing, and the motion parameters were used to compensate the position vector between frames of the electronic image of plaque, in order to improve the stability of the electronic plaque image.

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