Fast Video Stabilization Algorithm for UAV

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***Abstract*—Video captured from Unmanned Aerial Vehicles (UAV) usually suffer from undesired motion of the sensors, which severely defects detecting and tracking targets of interest. In this paper, a fast video stabilization algorithm for UAV is proposed to remove undesired motions and produce stabilized images. Firstly, a set of fast matching strategies are considered to match successive frames. Then, with motion parameters between two successive frames, a polynomial fitting and predicting method is proposed to estimate the global motion parameters and find out the undesired frames. After that, the undesired images are compensated. Finally, all frames are transformed to obtain stabilized images. Experimental results demonstrate the stabilization and the efficiency of the proposed algorithm.**

Keywords-- electronic video stabilization; circular block matching; polynomial fitting and predicting; image compensation

I. INTRODUCTION

An increasing number of UAV platforms are being equipped with streaming video solutions for immediate observation. The value of motion video information from mobile UAV platforms may be affected by the uncontrollable motion of the sensors[1]. Detecting and tracking targets of interest in such unstable motion video are very difficult, thus all of these video sequences should be stabilized to deal with mechanical vibration caused by engine parts.

Video stabilization techniques have been studied for decades, and many video stabilization schemes have been proposed, including two main methods classified by action principle[1]: mechanical video stabilization and electronic video stabilization. Mechanical video stabilization can't remove all video vibration and is very complex and expensive because of some necessary special equipment. Electronic video stabilization computes and compensates the deviation of images with some image processing techniques[2,3]. Comparing the two methods, electronic video stabilization is an ideal video stabilization technique which is more precise, flexible, inexpensive and easy to operate.

Motion estimation, which is used to estimate the global movement vector from the acquired video sequence, is the most important step of the process of electronic video stabilization, since its quality determines the effect of image compensation directly. Many algorithms have been proposed to obtain fast or precise motion vectors, such as optical flow estimation[4,5], edge pattern matching[6] , representative point matching (RPM)[7] and block matching[8,9] , etc. Among these algorithms, block matching is precise and reliable but with costly computation. In this paper, based on fast circular block matching strategy, a novel approach to motion estimation is introduced. It contains two steps: firstly, suitable blocks are chosen from the current frame to match with corresponding blocks of the reference frame; secondly, a novel polynomial estimation and prediction method is proposed to estimate the global motion parameters and find out undesired motion vectors. The proposed approach satisfies the specific requirements of a fast UAV video stabilization.

The rest of this paper is organized as follows: Section 2 introduces electronic video stabilization scheme, which consists of chapter2.1 motion estimation, chapter2.2 global motion parameters estimation and chapter2.3 image compensation. Section 3 presents the experiment and analysis, which includes charpter3.1 the robustness test for NCC matching method, chapter3.2 Result of fast Circular Block Matching (CB-NCC) and chapter3.3 Result for global parameters estimation and image compensation. Section 4 gives the conclusions.

II. ELECTRONIC VIDEO STABILIZATION SCHEME

As is widely accepted, electronic video stabilization can be basically subdivided into three steps[10] as displayed in Figure 1.

(1) Motion estimation.

This step is to estimate the camera motion parameters between frames and send them to the second step. Motion estimation determines the quality of the video Stabilization, and thus is asked to be reliable and real-time.

(2) Global motion parameters estimation.

This step is to estimate the global motion parameters.

(3) Image compensation.

This step is to stabilize the current frame, using the obtained global motion parameters.

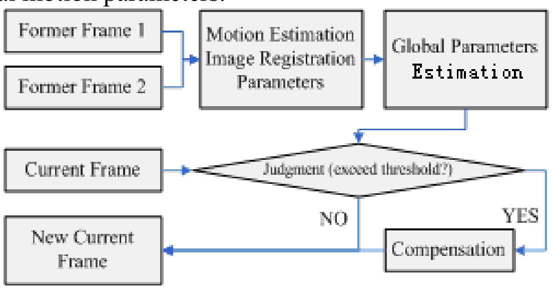

Figure 1 Scheme of UAV Video Stabilization

A. *Motion Estimation*

In the process of motion estimation, local camera movement vectors are necessary, of which several suitable motion parameters, including a horizontal translation, a vertical translation, a rotation and a scale component, are chosen to estimate the global camera movement vectors. Matching those four global motion parameters which are used to define displacement between two frames from new coming frame closely to previous one is the main task of motion estimation[1]. In fact, a perfect match is impossible in practice, since the background is unstable as the moving of camera and also,

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moving objects may appear in the scene. The goal of a good stabilization algorithm is to follow the moving background as closely as possible and to filter local motion in the output sequence that is not caused by the movement of the camera[1].

1) Fast Circular Block Matching Strategies

As the most important step of electronic video stabilization, motion estimation should be precise and real-time, and it is important to adopt the algorithm fast enough on the whole frame or on a large enough region containing enough information. Thus, here proposed a novel 'fast circular block matching' method-matching four circular blocks chosen as matching areas from current frame with corresponding blocks of the reference frame to get local motion vectors.

As is known, traditional image matching methods based on blocks matching usually perform on the whole frame and increase calculated amount. In order to estimate the motion vector between the current frame and the reference frame fast, four blocks with fixed size are selected in current frame. Unlike document [10], here we substitute rectangular blocks to circular blocks which are more robust to rotation. The center part of a frame should be excluded since the moving objects always appear in this area which severely defects matching accuracy. Also, to contain enough useful information in the each block, suitable boundaries in horizontal and vertical direction are excluded. The block selecting strategy is shown in Figure 2, where d_y and d_x respectively denote horizontal and vertical boundaries which should be excluded, and S_1^k S_2^k S_3^k and S_4^k denote blocks used for matching.

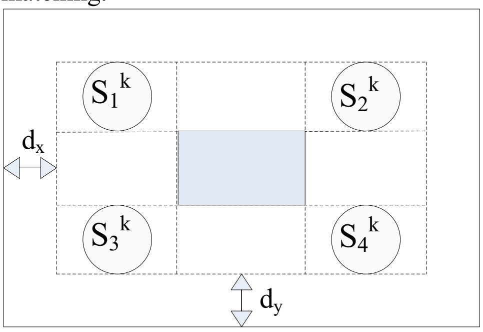


Figure 2 Selection of Matching Blocks in Current Frame

Area based matching methods[13], including Correlation-like methods, Fourier methods, Mutual information methods and Optimization methods, are commonly believed to be sensitive to the rotation and scale changes between images and cannot due with the situation when rotation and scale change significantly between adjacent frames. But considering the interval of two successive frames captured from UAV is usually less than 40ms and the rotation and scale change are small,, some of the area based methods can also be used as what will be demonstrated in chapter 3.1. Here, Normalized Cross-Correlation (NCC)[11] is adopted as similarity function to match corresponding blocks of successive frames, and its robustness to rotation and scale change are shown in section 3. Besides, in order to achieve a more fast algorithm, search scope is only enforced in a local area twice the block used for matching.

2) Motion Model

Each of the four blocks will find a matching position respectively, and fit to an Affine Model[12] which determines a motion vector between successive frames and can be solved by the least square method. The Affine Model is defined as follows,

$$\begin{bmatrix} x_i \\ y_i \end{bmatrix} = s \cdot \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \cdot \begin{bmatrix} x_j \\ y_j \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \end{bmatrix} \tag{1}$$

Where the parameter θ is the rotation, s is scale parameter, and T_x and T_y are the translations. Here, s is deemed as 1, because a sample interval within 40ms leads to small scale change between every two adjacent frames. Substituting all the four local motion vectors obtained in 2.1.1 into the motion model, it is easy to estimate the global motion vectors which consist of scale, rotation and translation parameters.

B. Global Motion Parameter Estimation

Compensation of the images can not be calculated directly only by the global motion parameters calculated in 2.1, since undesired motion of the sensors and normal motion of the UAV should be separated ahead of time. Normal motion of the UAV is apparently different from the undesired motion of the sensors-the former is slow and follows certain rules, while the other is fast and random yet unpredictable.

In view of different characters mentioned above, in this step, traditional methods usually adopt a low-pass filter to smooth motion parameters to maintain the low-frequency motion and reject the high-frequency motion. However, this method always leads to an undesired result that the stabilized images are several intervals falling behind the real video. Here, a polynomial fitting and prediction method (PFPM) is introduced to solve this problem, given by,

$$f(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \tag{2}$$

Given four parameters, then the fifth parameter can be predicted.

Define T as a threshold to filter out the undesired high-frequency motion:

If $\hat{f}(k \mid k-i) - f(k) > T$, the motion vector of frame i is undesired

Or $\hat{f}(k \mid k-i) - f(k) \le T$, the motion vector of frame i is desired

Where $\hat{f}(k \mid k-i)$ is predicted by the former motion parameters of $(k-i)$ frames; $i = 1,2,\ldots,4$. The value of T is set in accordance with the actual requirements.

C. Image Compensation

Image compensation, which uses filtered global motion parameters to compensate the current frame to obtain stable images, is the final step for video stabilization. The undesired motion frames illustrated in chapter 2.2 require compensation. The reverse formula (1) is used to determine compensation, of which the only difference is that the parameters here are estimated global parameters.

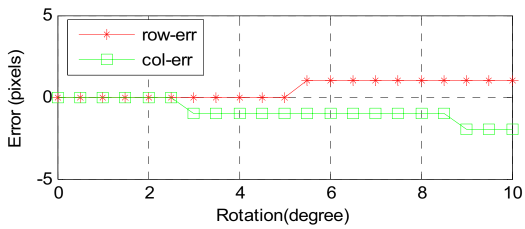
Because of the existence of position offset compensation, the size of frame after compensation is smaller than that of original, which brings appearance of blank areas in the compensated frame. It mentions several ways to fill in missing data in the borders in reference [1], in this paper, the way that keeping the old information of the previous video frames is chosen to solve the problem.

III. EXPERIMENTS AND ANALYSIS

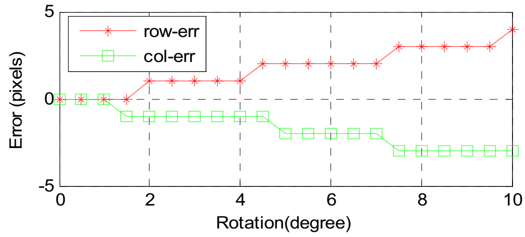
In this section, the robustness of the NCC method for matching which is the prerequisite condition for the whole stabilization scheme is firstly tested, followed by the test of effectiveness of proposed fast circular block matching strategy, and finally, the electronic video stabilization algorithm is tested by stabilization of images captured from UAV. Experimental platform is a Leno computer, of which the frequency and memory are respectively Pentium4 3.0GHZ and 1G, and the operation system is Windows XP. The whole set of program is wrote and run under matlab 7.1.

A. The Robustness Test for Matching Method NCC

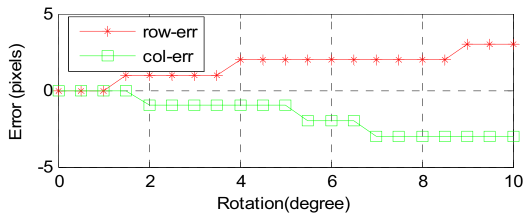
The following results given in Figure 3 are to show the performance of NCC matching method when rotation and scale changes exist between image-blocks taken from two successive image frames. As can be seen, the NCC method performs well when rotation parameter is smaller than 4 degree and the scale is range from 0.95 and 1.05 and thus can be applied to UAV video stabilization.



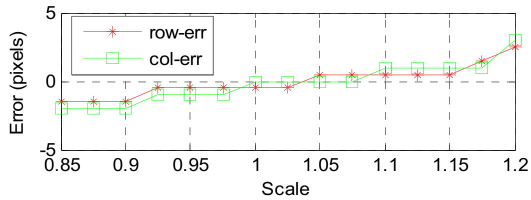
(a) Size20*20, Matching Errors vary with Rotation Changes



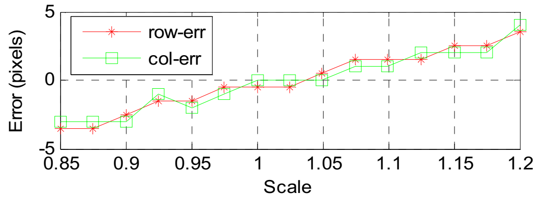
(b) Size30*30, Matching Errors vary with Rotation Changes



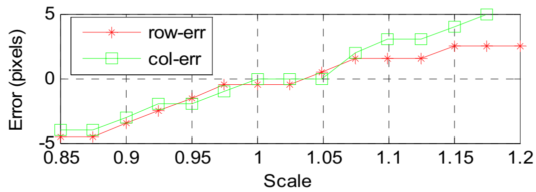
(c) Size40*40, Matching Errors vary with Rotation Changes



(d) Size20*20, Matching Errors vary with Scale Changes



(e) Size30*30, Matching Errors vary with Scale Changes



(f) Size40*40, Matching Errors vary with Scale Changes

Figure 3 Test for the robustness of NCC

B. Test for Fast Circular Block Matching (CB-NCC)

The following images are taken from a video captured from UAV employed with size of 216*300

(a)

(b)

(c)

Figure 4 (a) first frame, (b)second frame, (c) matching result

Figure 4 (a) and (b) show the original successive frames and (c) shows the result of matching (a) and (b). The estimated global motion parameters between (a) and (b) are: θ=1.5137 degree, T_x=-8.7500 and T_y=0.5000 pixels. The Edge of Image (b) is rotated and moved according to the obtained parameters above, and the results are add to (a) to get (c), then, the distinct result is shown in (c).

Using the two frames above in figure 4, the effects of several matching methods are compared in the following table. The theoretical precise parameters, θ=1.5128 degree, T_x=-8.8930 and T_y =0.5160 pixels are calculated with matching points chosen manually.

TABLE I. THE COMPARISON AMONG MATCHING METHODS

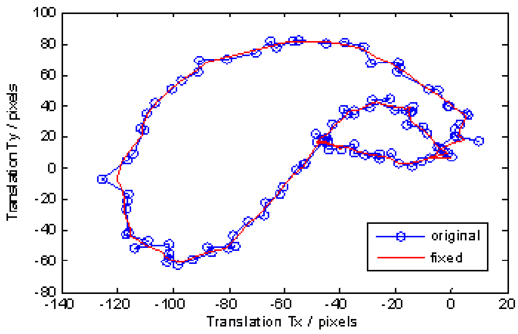
Methods	Translation / Error	Rotation / Error	Time
B-NCC	(-3.92,1.33) / (4.97, 0.74)	1.24 / 0.56	7.657s
NCC	(-8.00,0.00) / (0.89,0.59)	NC	1.024s
MI	(-8.00,1.00) / (0.89,0.59)	1.40 / 0.20	13.05s
HD	(-8.00,1.00) /(0.89,0.59)	NC	3.486s
RB-NCC	(-8.868,0.55)/(0.03, 0.05)	1.5090/0.04	0.109s
CB-NCC	(-8.750,0.50) / (0.14,0.02)	1.5137/0.01	0.112s

Note: B-NCC – Block Matching with NCC, search in the whole image; NCC – search in the whole image; HD – Hausdorff Distance on edge map; RB-NCC – Rectangular 4 block matching, search locally; CB-NCC – Circular 4 block matching proposed in this paper, search locally. NC means that the rotation parameters can't be calculated.

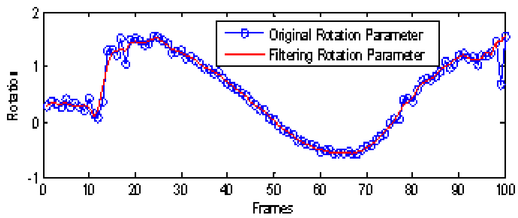
From the test results, the CB-NCC and RB-NCC is faster than other methods, and CB-NCC is more precise. Thus it is obviously better to used CB-NCC to calculating the motion parameters.

C. Test for Global Parameters Estimation and Image Compensation

Following method is tested on the sequences acquired from UAV, 100 frames of which are employed with size of 216×300. Figure 5 shows the original global motion parameters and corresponding estimated global parameters (motion parameters for compensation).



(a) Translation parameters



(b) Rotation parameters

Figure 5 Results of initial and global motion parameters

Compared to a low-pass FIR Filter, this method performs better, which is shown in Table 2.

TABLE II. THE COMPARISON BETWEEN PFPM AND SEVERAL OTHER FILTERS

Filter Method	window size	description	Mean Square Error		
			Tx	***Ty***	***Rotation***
FIR Filter	3	[1 1 1]/3	2.5926	6.8219	1.2708
	4	[1 1 1 1]/4	4.1996	11.0330	1.8798
	5	[1 1 1 1 1]/5	5.9691	16.1438	2.4989
PFPM	------	------	1.8955	1.932	0.0470

The global motion parameters T_x, T_y and θ are estimated after matching every two successive frames, shown as in Figure 5. Due to the existence of undesired jitter motions, the motion vectors in some frames are not smooth, as shown through lines with circle on it. To smooth the motion vectors, a threshold is set to filter out the unpredictable motion, and then the images are compensated by filtered global motion parameters.

Image compensation equates image transformation with the global parameter.

(a) frame 35 (b)frame 36

(c) frame 37 (d)compensated frame

Figure 6 Result of compensation (frame 37 is compensated)

IV. CONCLUSION

A modified way to selects several circular blocks in current frame to match former frame is proposed, the feasibility of matching method NCC and the better robustness of electronic video stabilization scheme with circular selective blocks are demonstrated, polynomial fitting is used to estimate global parameters. In future, we will focus on improving motion estimation method to acquire a better performance.

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