Real-Time Video Stabilization for Aerial Mobile Multimedia Communication

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Abstract—**This research develops the video stabilization system for First Person View (FPV) in order to reduce the vibration both in vertical and yaw axis of camera motion. Generally, video stabilization system is the technique to improve the quality of video sequences arising from an uncontrollable motion of the capturing camera. The real-time video stabilization scheme is introduced to stabilize video sequences transmitting from Unmanned Aerial Vehicles (UAV) operated in the surveillance mission. Clearly, the multimedia communication system consists of CMOS camera, a video transmitter and a receiver module. A video sequence is transmitted to a receiver at the ground control station, and a raw video is processed and displayed on a ground monitor. Also, this system can be improved for the FPV. However, the shaking image in vertical and yaw axis hardly effects to the pilot. As a result the FPV system has to be stabilized particularly in vertical and yaw axis. This research improves the FPV by using the smart optical flow algorithms, Pyramid Lucas-Kanede. The advantage of this research is to reduce parameters and faster computation. This system can be used as a surveillance video or as a part of the First Person View (FPV) for a RC video control.**

Index Terms—**Video stabilization, motion estimation, optical flow estimation and motion compensation.**

I. Introduction

Today, military and civilian technology are advanced and developed rapidly. Unmanned Aerial Vehicle (UAV) and Bomb Disposal Robot (BDR) are two importance technologies developed in the last two decade. They represent two important modern technologies in the modern warfare with unmanned operations resulted in quick operations, reduced risk and loss of human operators.

During UAV or FPV missions, the operator observes the video sent by the air flying aircraft. Especially in the FPV system the operators need the have a clear image displayed in the virtual cockpit. For UAV system, the video must have a good quality and reliable to guarantee the success of the mission. In the real environment, the actual video sequence is distorted by the running engine, which produces vibrations to shake a camera in the vertical axis and yaw axis. Also, the effect from the turbulence wind causes the camera to vibrate. The vibration and tilt of the aircraft will shake, blur and rotate image. So the system is needed to have a video stabilization for FPV control to improve the quality of the corrupted video sequence.

Video stabilization is a process of video enhancement to reduce unstable or undesirable video sequences. The video stabilization technique is of great significance to the UAV application. Without video stabilization system, the video obtained from camera installed in the UAV will be trembled while the UAV is moving. Therefore, it is necessary to develop a technique to stabilize a video. The stabilization can be implemented on the UAV or the ground control station.

At present video stabilization techniques are investigated by researchers over a period of five to ten years and proposed a number of techniques and algorithms. It can be divided into two categories, hardware (mechanical) and software (computer program) techniques. Hardware technique is implemented using mechanical devices to reduce the vibration of the structure holding the camera. But this technique can not remove all vibrations because in some cases the vibration or unstable frame does not come from the vibration of structure or rapidly movement of UAV. This technique is complicated and cost a lot of money and time to implement . In case of software technique, it costs less than the hardware technique because it does not require special equipment and this technique uses computer software to output the stabilized the video sequence. The algorithms compute and compare the difference between target frame (current frame) and previous frame and then find and predict parameters from difference parameter. Finally target frame are compensated and rebuild before sending out.

The global movement vector between target frame and previous frame and translational camera motion acquired from video sequence are computed by "Motion Estimation" which is the most important step in video stabilization technique. Many motion estimation algorithms have been proposed such as optical flow [1, 2, 3] estimation but it is too sensitive to noise. Phase-correlation based motion estimation [4] does not appropriate with real-time computation because it needs many computations. Edge mapping [5] , block matching such as: point matching, edge pattern matching, gray-coded bit-plane matching [6, 7, 8] have a precise criteria and reliable but has a costly computation.

In the next several sections of the paper, we proposed strategies toward optical flow estimation algorithms to be suitable for a real-time video. The algorithm separates target frame and previous frame into small blocks and matches between two blocks to find the optical flow vector. The compensation of FPV control will be used in the pan and boom direction (Translation) because the pan and boom direction create vibration and blur image. The angle of rotation is not used to compensate image because the rotation image will indicate the tilt of aircraft.

The Paper begins with the video stabilization methodology in section II. Then Section III gives experiment results of real-time stabilization for many scenerios.

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II. Video Stabilization Methodology

A. First Person View (FPV)

First Person View (FPV) is a method used to control a remote-radio controlled vehicle, most commonly used by a pilot who controls the UAV at the ground control station. Fig. 1 shows the FPV control setup which controls UAV by using the first person perspective image sent from the camera on UAV to ground control station. The image is shown on the monitor screen as if the pilot is sitting in the UAV and looks on the scene in front of his cockpit.

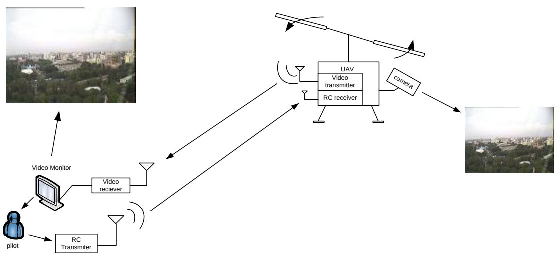

Fig. 1. FPV control diagram

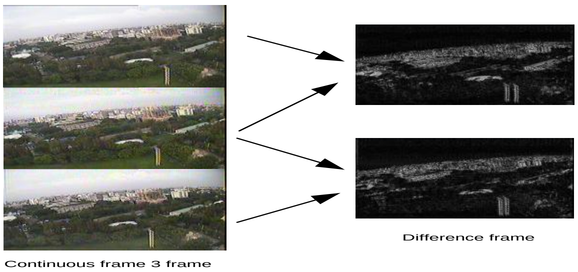

Fig. 2. FPV display

In Fig. 2, three continuous frames look very similar, but their differences can be found as seen more closely at images on the right hand side. The differences are caused by the vibration of the engine and wind in the vertical and the yaw axis direction.

B. Flow chart of overall system

Fig.3 shows overall flow chart of video stabilization system which is divided into 2 main steps. However, each main step can be divided into sub steps as showed in Fig. 3 Each block in Fig. 3 will be explained in the next section.

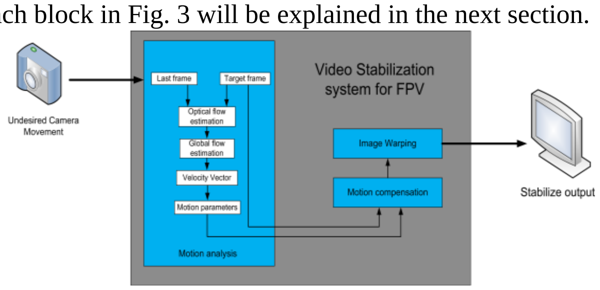

Fig. 3. flow chart of video stabilization

C. Aerial Vehicle & Camera Motion

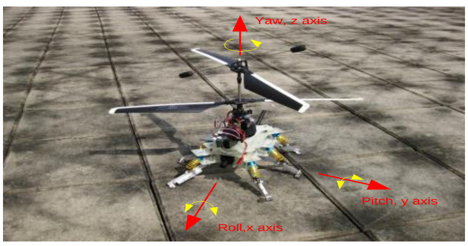

Fig. 4. Aerial Vehicle Direction

As Shown in Fig. 4 aerial vehicle attitude is divided into three motion angles which are roll, pitch and yaw. Roll, pitch and yaw angles specify the motion around x, y and z-axis, respectively.

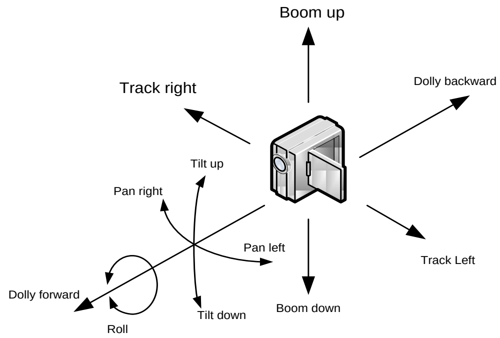

Fig. 5. Typical type of camera motion [9]

As aerial vehicles are moved, the camera attached to its body will move in the same direction as the aerial vehicle. The camera motion in the forward-backward direction is called Dolly direction. The movement in the left-right direction is called Track, and the movement in the up-down direction is called the Boom. As shown in Fig. 5, the vibration of camera will result in the low quality of the intended video.

D. Motion Model

The Mathematical model for stabilizations can be divided into three types [10].

1) The camera is in fixed position, but the image is moved.
2) The image is stationary, but the camera is moved.
3) Both image and camera are moved.

In general, the camera is setup on the aircraft such that the rotation of the image is depended on the rotating of camera. However, the higher altitude results in the smaller image. Obviously, this image is shown as a still image. As described above, the mathematical model can be represented as the following equations [11]

$$[X]' = \{[R]\cdot[X]\} + [T] \; ; \; [X]' = \begin{bmatrix} x' \\ y' \end{bmatrix}, [X] = \begin{bmatrix} x \\ y \end{bmatrix} \quad (1)$$

and

$[X]'$ = Pixel in present frame,

$[X]$ = Pixel in previous frame

$[T]$ =Translation vector $(T_x, T_y, T_z)^T$.

In case of video stabilization, T_z equal to zero. $[R] = [R_x]\cdot[R_y]\cdot[R_z]$ isa rotation matrix which rotates a point around axis X, Y and Z. Each rotation in each axes can be presented as a rotation matrix as follows

$$[R_x] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_x & -\sin\theta_x \\ 0 & \sin\theta_x & \cos\theta_x \end{bmatrix} \quad [R_y] = \begin{bmatrix} \cos\theta_y & 0 & \sin\theta_y \\ 0 & 1 & 0 \\ -\sin\theta_y & 0 & \cos\theta_y \end{bmatrix}$$

$$[R_z] = \begin{bmatrix} \cos\theta_z & -\sin\theta_z & 0 \\ \sin\theta_z & \cos\theta_z & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Finally, the generalize rotation matrix $[R]$ is

$$[R]=\begin{bmatrix} \cos\theta_y\cos\theta_z & \sin\theta_x\sin\theta_y\cos\theta_z-\cos\theta_x\sin\theta_z & \cos\theta_x\sin\theta_y\cos\theta_z+\sin\theta_x\sin\theta_z \\ \cos\theta_y\sin\theta_z & \sin\theta_x\sin\theta_y\sin\theta_z+\cos\theta_x\cos\theta_z & \cos\theta_x\sin\theta_y\sin\theta_z-\sin\theta_x\cos\theta_z \\ -\sin\theta_y & \sin\theta_x\cos\theta y & \cos\theta_x\cos\theta_y \end{bmatrix}$$

and the rotation matrix is an orthonormal matrix

$$[R]^{-1}=[R]^T \quad \det[R]=\pm 1$$

In case of the unstable camera, the motion of the camera is in pan, tilt, and the translation (Track and Boom). It follows that

$$\begin{bmatrix} x' \\ y' \end{bmatrix}=\begin{bmatrix} \cos\theta_z & -\sin\theta_z \\ \sin\theta_z & \cos\theta_z \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix}+\begin{bmatrix} T_x \\ T_y \end{bmatrix} \qquad (2)$$

It can be seen that the equations are in linear and easy to estimate the motion for both global and local coordinate.

E. Motion Analysis

Motion analysis is the most important step in the image stabilization and motion estimation. The scheme requires at least two frames (the present and the previous one) There are many analysis methods but in this research, the optical flow method will be implemented. The first step in the optical flow scheme is to find the local motion estimation, and the final step is to find the global motion estimation or the global flow which will indicate the shift and the rotation of the picture. Optical flow reflects the image changes due to the motion during a time interval dt. It represents the optical flow field or the velocity field of the three-dimensional motion of objects pointed across a two-dimensional image. There are three assumptions [12] for optical flow computations.

1) Brightness constancy
2) Temporal persistence
3) Spatial coherence

The optical flow computation method called Pyramid Lucas-Kanade[13] will be used in this research. The 2D optical flow is obtained by

$$\frac{\partial I}{\partial x}u+\frac{\partial I}{\partial y}v+\frac{\partial I}{\partial t}=0 \qquad (3)$$

u and v is denote the horizontal and vertical velocities.

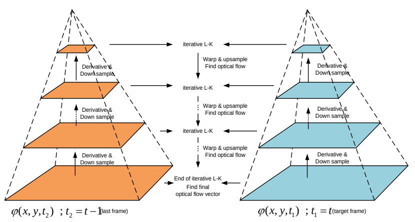

Fig. 6. Coarse to fine optical flow estimation

For each level of PLK computation,

$$\begin{bmatrix} u \\ v \end{bmatrix}=(A^TA)^{-1}A^Tb \qquad (4)$$

The obtained velocity vector will be processed and the error at the boundary will be eliminated. After that the velocity vector and the distance from point to point will be used to compute the angular change to indicate the change of the whole picture.

F. Motion Compensation

The motion compensation is a final step for the video stabilization, which compensates the undesired frame shift between target frame and the previous frame. The inversed (2) is used to calculate the compensation. In FPV case, control parameters in (2): the rotation angle (θ_z) is not brought to compute in equation and the rotation angle is assumed to be zero (not rotate) because the pilot notices the rotated image. It means the pilot knows the tilt of aircraft and can prevent the UAV to fall.

III. Experiment and Results

The camera and video transmitter is installed in the small coaxial-helicopter (Big Lama) and controlled by radio controlled (RC) in the outdoor using FPV type control. The experiments were tested at Rugby fields in Kasetsart university campus, and parameters of the camera were set in the program as follows: The camera operates in 10 fps with a VGA type (320 x 240). The first experiment is to find the optical flow vector and the difference frame between target frame and previous frame. Fig. 7 shows the target frame, previous frame, and the optical frame (row 1, 2, 3).

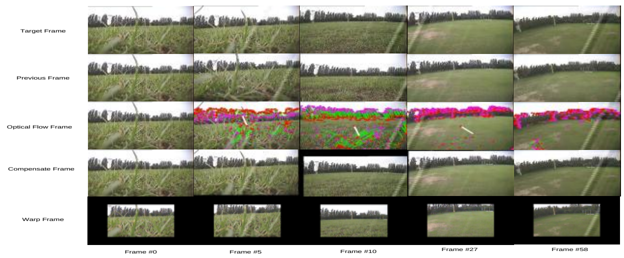

Fig. 7. Target, Previous, Optical flow, Compensate, Warp frame of Frame 1, 5, 10, 27, 58

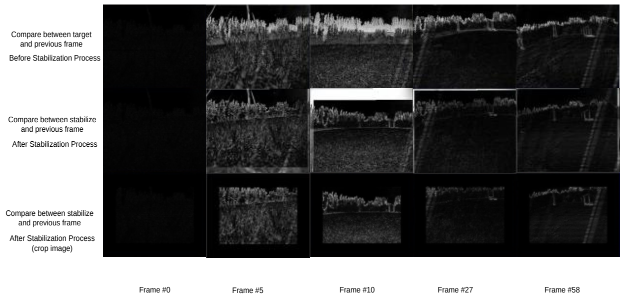

Fig. 8. Difference before and after stabilization process of Frame 1, 5, 10, 27, 58

In Fig. 7, the target frame and the previous frame were compared to determined difference. If either target frame or previous frame is moved from present location as in Fig.8, the difference frame before stabilize process (first row) will be overlapped. For this reason, the optical flow can be found and calculated resulted in the global flow of the image. In the optical flow frame, the red points (points of pixel in the previous frame) are used as a reference point to move to the pink points (points of pixel in the target frame). The direction between point to point is showed by green line. If the image is observed more closely, It can be seen that some optical flow did not go to the same direction, which will affect the global flow, and the error at the boundary will be filtered out to prevent the occurrence of global flow error. The global flow is shown with the white line in the center of the image with a red head direction. And shown in Fig.8, after the stabilization the difference frame (second row) has the little overlapped which means the stabilization frame has approximate directions to previous frame, and the 3rd row compare the warp image and previous in same high and width of the image. Fig. 9, 10 shows frame 79, 125, 145, 173, 207.

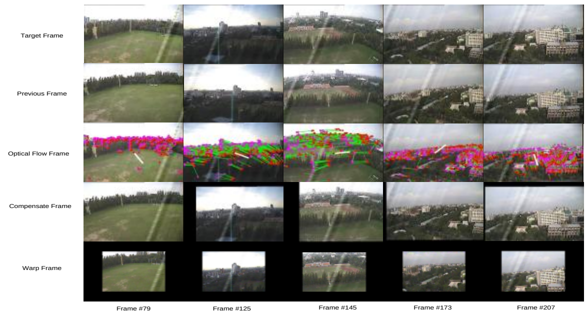

Fig. 9. Target , Previous, Optical flow, Compensate, Warp frame of Frame 79, 125, 145, 173, 207

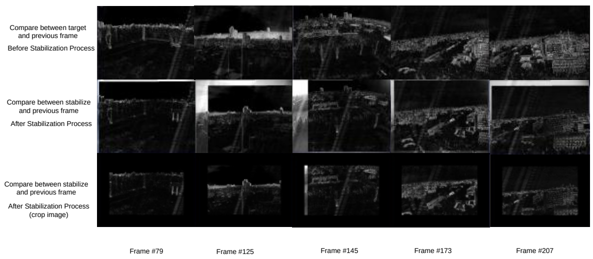

Fig. 10. Difference before and after stabilization process of Frame 79, 125, 145, 173

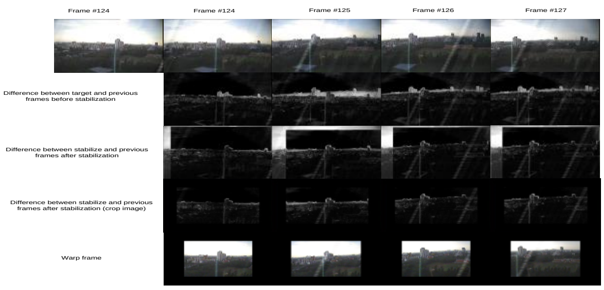

Fig. 11. 4 Consecutive frames difference before/after stabilization process of Frame 123 - 127

In Fig. 11, the 4 consecutive frames calculated and shows the difference between target-previous (before stabilization) and stabilized-previous frame (after stabilization).

After the global flow is calculated, the direction (translation T_x, T_y) and rotation) angle (of image will be obtained. In this case the image error will be compensated for the case of the aerial vehicle controlled by FPV. The serious effects with the FPV control is the vibration of engine, which vibrates in the vertical and yaw axis. Also the wind direction will cause the tilt of the aerial vehicle.

Results show that the engine vibration has more effect than the wind and this effect results in the unwanted motion of the camera. The camera effect will be in the boom (vertical axis) and the pan axis (yaw axis). As shown in Fig.7 and Fig.9, the compensated (row 4) shift will be along the x- and y axis in the reverse direction of the white line in optical flow frame. However, the resulted compensation is good enough for the FPV control.

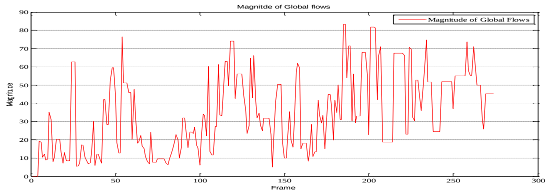

Fig. 12. Magnitude of vectors

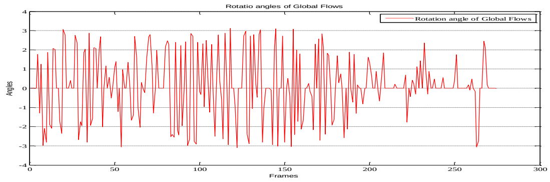

Fig. 13. Rotation angles

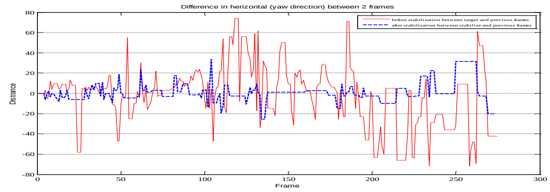

Fig. 14. Frame shift of x axis

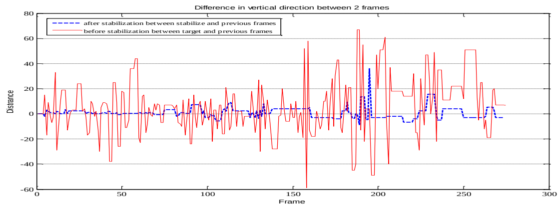

Fig. 15. Frame shift of y axis

Fig. 12, 13, 14, 15 show magnitude of vectors, rotation angle, frame shift of x axis, and frame shift in y-axis, respectively. Fig. 14 and 15 show the frame shift of the x axis and y axis, respectively. The red line shows values before the stabilization (between target and previous frames). The blue line shows values after the stabilization (between the stabilized and previous frames). The blue line indicates the lower value compared to the red line.

IV. Conclusions

A video stabilization algorithm is developed, and implemented with practical video systems. The system consists of a camera, wireless video transmitter, video receiver, and a PC. The optical flow video is displayed. Fig 9, 10, 11, 12 shows that while the aircraft is operating, the undesired camera motion resulted from the wind, the engine, and all surrounding environments. The presented algorithm can reduce error to an acceptable level for FPV control. Finally, this prototype system can be used as a surveillance video or as a part of the First Person View (FPV) for a RC video control.

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