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Research on Image Motion Blur for Low Altitude Remote Sensing

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Abstract: The high resolution images can be acquired by an Unmanned Aerial Vehicle (UAV) flying at low altitude. Because of air turbulence and unstable flight conditions, the motion blur amount caused by the UAV system is more complex than the manned professional aerial platforms. To meet the potential demand of high resolution remote sensing applications, both theoretical and quantitative analysis were conducted about the factors which caused image blur.It is proposed that the forward blur still occupied the leading position of the whole motion blur amount. However, the bigger attitude angles enlarged the forward motion blur amount at image edges. Moreover, the motion blur caused by the larger angular velocity within the exposing time could not be neglected. Finally, quantitative experiments on low altitude UAV remote sensing indicated the camera angles and angular motion in roll, pitch and heading direction should be controlled with quantitative values in order to decrease the motion blur of images from UAV.

Key words: Motion blur , unmanned air vehicle, collinear equation, image processing, remote sensing

INTRODUCTION

In recent years, the low cost UAV system has become very attractive potential alternative to satellite and professional aerial platforms .UAV has been increasingly adopted by civil applications including remote sensing for assessment of natural disasters and environmental monitoring (Aerometrex, 2012), firefighting, detection of mines and explosives, rapid emergency response operations and 3D terrain mapping (Cui *et al*., 2008) etc. Because of light weight ,low cost SLR cameras with high resolution have been used as the onboard imaging systems. The cameras are required to provide superior image quality and the level of detail needed from an aerial image. However, one of the main problems influencing image quality is the blur of the image caused by sideways, rotational and forward motion of the camera during exposure. Image motion compensation and the resulting image blur has been addressed in computer vision and remote sensing and mapping industries.

Existing blur detection algorithms often require additional information associated with both the image and image acquisition., feature tracking has been carried out based on extracting the 3D motion of the camera. Some research also were conducted to decrease the image motion blur using an Inertial Measurement Unit (IMU) to acquire the attitude information (Shah and Schickler, 2012; Sieberth *et al*., 2013). As both electro magnetic and radio devices in UAVs (Cheng *et al*., 2012) can influence the IMU output rates and its accuracy, relying on IMU data for estimating the PSF will be unreliable in UAV remote sensing or photogrammetry Sieberth *et al*. (2013). Also other hardware devices like "Forward Motion Compensation" (Pacey and Fricker, 2005) or image stabilization platform are difficult to include in a light weight UAV at low cost. In fact it is difficult to make the downward facing camera must be absolutely aligned to a 90 degree angle relative to the ground in UAV. However, this paper aims at quantifying the image motion blur amount and proposing low cost methods r avoiding blurred images from UAV's.

QUANTITATIVE ANALYSIS OF IMAGE MOTION BLUR

The main problem of existing algorithms is that the blur in the images cannot be quantified which prevents to develop the feasible method to automatically avoid acquiring blurred images.

Forward image motion blur: The perspective geometry is established by the collinearity condition which states that the perspective center, the object point and the corresponding image point must be collinear (Fig. 1).

When an object point P $(X, Y, Z)^T$ in object coordinate system is projected into an image point p(x,y) in image space coordinate system at the exact time t_0 then we can get following equation:

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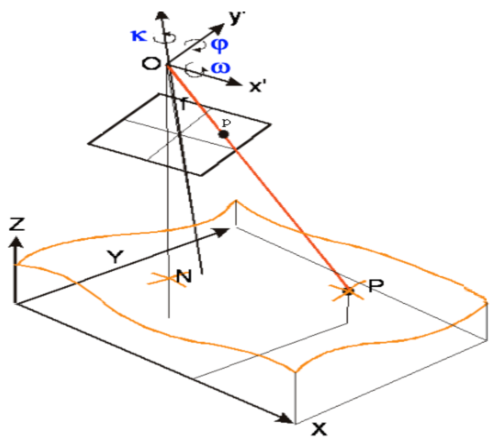

Fig. 1: Photographing geometry

$$\begin{bmatrix} X_p - X_s \\ Y_p - Y_s \\ -H \end{bmatrix} = \lambda' R^T \begin{bmatrix} x \\ y \\ -f \end{bmatrix} \quad (1)$$

Where:

$$R = \begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{bmatrix}$$

$$a_1 = \cos\varphi\cos\kappa - \sin\varphi\sin\omega\sin\kappa; b_1 = \cos\omega\sin\kappa;$$
$$c_1 = \sin\varphi\cos\kappa + \cos\varphi\sin\omega\sin\kappa; a_2 = -\cos\varphi\sin\kappa - \sin\varphi\sin\omega\cos\kappa;$$
$$b_2 = \cos w\cos\kappa; c_2 = -\sin\varphi\sin\kappa + \cos\varphi\sin\omega\cos\kappa;$$
$$a_3 = -\sin\varphi \text{Cos}\omega, b_3 = -\sin\omega, c_3 = \cos\varphi\cos\omega$$

Suppose UAV flies at constant velocity during exposing time Δt, Blur δ_f caused by the forward movement of the UAV can be computed at the exact time $t_0+\Delta t$ using the following equations:

$$\begin{bmatrix} X_p - V_f \bullet \Delta t - X_s \\ Y_p - Y_s \\ Z_p - Z_s \end{bmatrix} = \lambda R^T \begin{bmatrix} x_p' \\ y_p' \\ -f \end{bmatrix} \quad (2)$$

$$\delta_f \approx x' - x = \frac{V \cdot \Delta t}{a_1 \cdot H}(c_3 f - c_1 \cdot x - c_2 \cdot y) \quad (3)$$

Where for an image:

δ_f = Motion size in pixel
V = Linear ground speed for the image in m/s at the time of exposure
Δt = Exposing time
f = Focal length in mm
H = Flying height above ground in meter

If the cameras in the UAV can be set facing downward during exposing, an image is created where the scale is constant over the entire image. The equation is often simplified as:

$$\delta_f = \frac{V \cdot \Delta t}{H} f$$

However it is impossible to make the camera perfectly aligned to a 90 degree angle relative to the ground in UAV as a result of air turbulence and unstable flight conditions. So it is important to give the quantitative analysis of the image blur introduced by the forward motion of the UAV with large attitude angles.

Image motion blur caused by angular motion: Supposing, at the exact time t_0, the attitude angles are φ_0, ω_0, k_0 and the corresponding angular speed are v_φ, v_ω, v_k UAV flies at constant angular velocity during exposing time Δt ,the angles would be changed to $\varphi = \varphi_0+\Delta\varphi$, $\omega_0+\Delta\omega k = k_0+\Delta k$.

The object point P (X, Y, Z) is projected into an image point p'(x,y) in image space coordinate system at the exact time $t_0+\Delta t$, p(x,y) at the opening of the shutter t_0. The relationship between p'(x,y) and p(x,y) is:

$$\begin{bmatrix} x' \\ y' \\ -f \end{bmatrix} = \lambda \begin{bmatrix} \cos\varphi & 0 & \sin\varphi \\ 0 & 1 & 0 \\ -\sin\varphi & 0 & \cos\varphi \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \end{bmatrix} \begin{bmatrix} \cos k & \sin k & 0 \\ -\sin k & \cos k & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ -f \end{bmatrix}$$

If $\Delta\omega = \Delta k = 0 \Delta\varphi \neq 0$ and $\Delta\varphi$ is very small, we can get the following equation:

$$x' = f\frac{x - f\tan(\Delta\varphi)}{f + x\tan(\Delta\varphi)}, y' = \frac{f}{f + x\tan(\Delta\varphi)} y$$

Because of the small value of tan ($\Delta\varphi$),the blur caused by angular movement in pitch direction along x-axis $\delta_r(x_\varphi)$ and y-axis $\delta_r(x_\varphi)$ can be simplified as:

$$\delta_r(x_\varphi) = x' - x \approx f \bullet \tan(\Delta\varphi)$$

$$\delta_r(y_\varphi) = y' - y \approx -\frac{xy\tan(\Delta\varphi)}{f + x\tan(\Delta\varphi)} \approx -\frac{xy}{f}\tan(\Delta\varphi)$$

The total differential equation can be derived:

$$d\delta_r(\Delta\varphi) = f \bullet \sec^2(\Delta\varphi)d\varphi$$

Thus, equation.5 is derived as following:

$$\delta_r(x_\varphi) = f \bullet \sec^2(\Delta\varphi) \bullet v_\varphi \bullet \Delta t \quad (5)$$

$$\delta_r(y_\varphi) = -\frac{xy}{f} \bullet \sec^2(\Delta\varphi) \bullet v_\varphi \bullet \Delta t$$

In the same way, when $\Delta\varphi = \Delta k = 0$, $\Delta\omega \neq 0$, the blur caused by the angular movement along roll direction $\delta_r(\omega)$ and heading direction $\delta_r(k)$ can also be calculated.

From the Equation 5 , the blur caused by angular movement depends on angular velocity and exposing time. Depending on turbulence encountered, the angular velocity of the UAV can reach up to 200/s (3.5 rad/s), this means it takes 1.8 s for one revolution which is normal for a typical low weight fixed-wing UAV (Chabok, 2013). In such case, image blur caused by angular movement cannot be omitted. To decrease the blur caused by angular motion it is important to ensure the smaller angular velocity and shorter time during camera exposing.

Quantitative analysis: For example, the amount of blur caused from sideways and forward motion of a typical fixed-wing UAV can be calculated as follow with assuming:

Cruise speed: 30 m sec^{-1}
Camera shutter speed: 1/1000 s
Camera's sensor size: 8.2 micron
Focal length: 24 mm
Flying height: 300 m

When $\varphi_0 = \omega_0 = k_0 = \Delta\omega = \Delta k = 0$, $\Delta\varphi = 0$, using the Equation (3) the forward motion blur will be 0.2927pixels which is smaller than 1/3 pixel. In fact, the attitude angle cannot be zero degree, so the forward motion blur of every pixel on the image is different both in direction and size. Take the central image point to represent the center area of the an image, the size of image blur can be calculated as Table 1.

In the same way, this calculation can then be done for the four corners of an image, the direction and the size of the motion blur can be shown in Fig. 2.

The experiments show that the forward image blur can be neglected at central area of an image in spite of large attitude. However, at the edge of an image, the heading angle of k did little impaction on the image blur,

Table 1: Image blur amount

φ (°)	ω(°)	k (°)	Image blur (pixel)
5	5	5	0.2929
10	10	10	0.2943
15	15	15	0.2982
20	20	20	0.3066
25	25	25	0.3223
30	30	30	0.3512

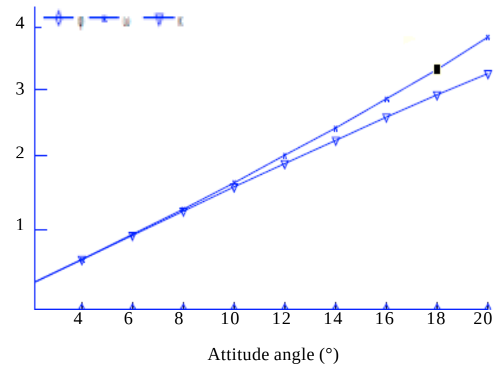

Fig. 2: Forward image motion blur at edge of an image

when roll or pitch angle exceeds 6° ,the forward image blur will more than one pixel which seriously degrades the image quality. Thus, the image blur caused by forward motion can not be simply evaluated by Equation(4) in which the factors of large oblique angles during camera exposing are not considered.

Suppose without the forward image blur and only the image blur caused by pitch angular movement is considered and $\varphi = 30°$, $\omega_0 = 30°$, $k_0 = -10°$, $\Delta\varphi = 0.001$, the image blur amount for every image point in an image can be calculated by Equation (4). The maximum image blur in x-axis direction is only 0.08pixels and 0.02pixels in y-axis direction. However, the image blur will attain to 0.33pixels in x direction and 0.1pixels in y direction with assuming $\Delta\varphi = \Delta\omega = 0.001°$, $\Delta k = -0.001$. In the same ways, theimage blur amount only related to roll or heading direction can be calculated. Moreover, consider three angular movement with assumption $\Delta\varphi = 0.003°$ that the maximum image blur amount caused is no more than 0.1pixels both in x-axis and y-axis direction. The size and direction for the image blur amount can be calculated and shown in Fig. 3a~d.

For aerial photographing at low altitude it was concluded that the image blur amount can be neglected if every angular velocity of the UAV was no more than 0.01 rad/sec, however The blur amount caused will exceed 1/3pixels with the angular velocity of the UAV in every direction attaining to 0.05 rad/s and can not be neglected for high resolution remote sensing.

COMPESATION ANALYSIS

From the above quantitative analysis, even if a very short exposure time and high flight altitude were used , the image blur amount can not be neglected because of the existence of large angles in pitch, roll or heading direction and the angular movement during exposing time.

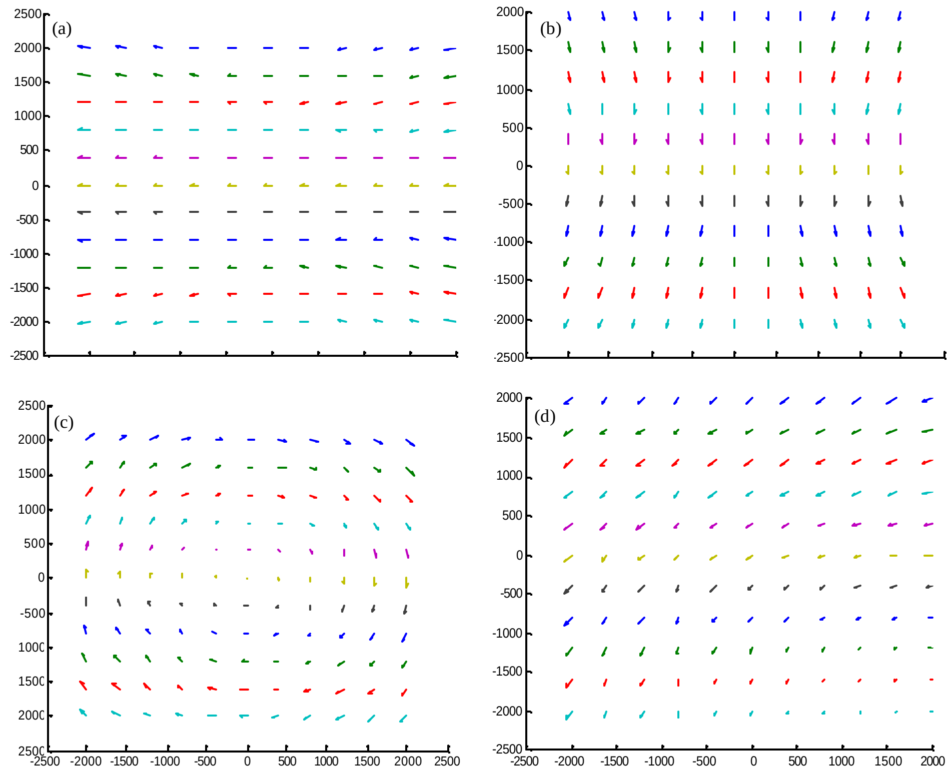

Fig. 3(a-d): Size and direction of the motion blur in a image caused by angular motion (a) $\Delta k = \Delta\omega = 0°$, $\Delta\varphi = 0.001°$, (b) $\Delta k = \Delta\varphi = 0°$, $\Delta\omega = 0.001°$, (c) $\Delta\varphi = \Delta\omega = 0°$, $\Delta k = 0.001°$ and (d) $\Delta\varphi = \Delta\omega = 0.001°$, $\Delta k = 0.001°$

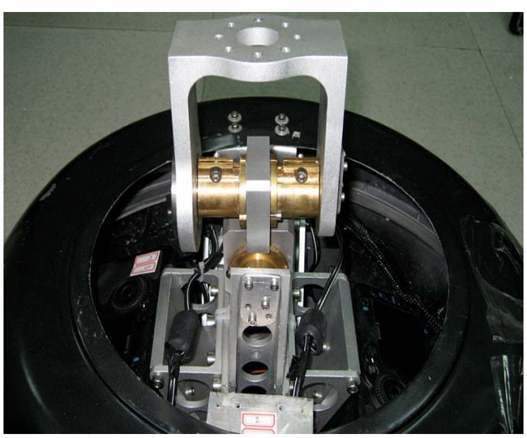

Fig. 4: Three-axis stabilization platform

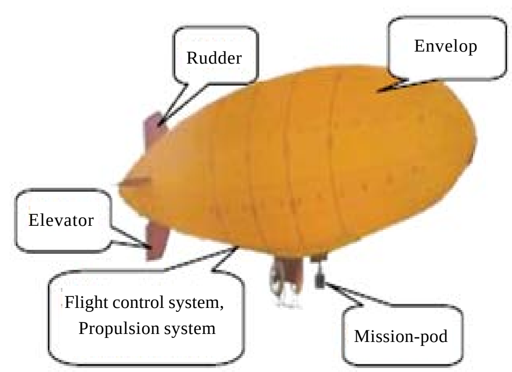

Fig.5 Unmaned airship system

Although it is difficult to make the downward facing camera must be perfectly aligned to a 90° angle relative to the ground. It is needed to decrease the camera angles in pitch, roll and heading direction within 3 degrees and every angular velocity was limited to 0.01rad/sec to ensure the image quality. Thus, the three-axle stabilized platform have been developed in Chinese Academy of Surveying to meet the requirements The CCD digital camera is mounted on the platform and an auto-control system is developed to control camera exposure and adjust the rotation of the three-axle platform (Fig. 4).Using such a photographing system on the UAV (Fig. 5) to isolate UAV angular motion and meet the needed requirements for the above quantitative analysis

Fig. 6(a-b): Subsection of an image with motion blur (left) and the de-blurred image result (right) of an image with controlled stabilized platform and shorter exposing time

and adopting a shorter exposing time, the images have be acquired with more recognized detail information (Fig. 6).

CONCLUSIONS

This paper has outlined the development of an algorithm to evaluate the image motion blur with quantitative analysis in UAV remote sensing system. It is conclude that motion blur cannot be calculated by simple equation in which the angular factors are neglected. This makes it possible to develop hardware devices for acquiring high quality images and motion blur correction algorithms for further data processing. The quantitative algorithm is reliable and experiments show that the method developed according to the quantitative results is effient and feasible for UAV remote sensing applications.

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