Adaptive Motion Compensation:
A Modern Approach

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Introduction

Motion compensation in general and forward motion compensation in particular was an important milestone in aerial imaging when it was presented for film-based camera-systems in the late 90s of the last century. It focused on forward motion compensation to enhance the image quality when flight speed and image scale produce such motion blur, even when the exposure time was short.

When digital aerial cameras replaced the film-based camera systems in the first decade of the 21st century, forward motion compensation (FMC) could be implemented as an electronic feature of the CCD sensors, namely the time delayed integration (TDI) feature, which worked fine and did not require a mechanical component. Not all cameras could make use of that but large format frame cameras like DMC and UltraCam were able to compensate forward motion blur exploiting this feature of the electronic sensor component.

Since C-MOS sensors were replacing the CCD sensor component of digital aerial cameras, there was a need to implement the FMC mechanism by other solutions. One approach was based on a mechanical device, able to move the sensor along the flight path of the aircraft, like it was done for film cameras.

At that time Vexcel Imaging decided to develop a more versatile approach based on software and without any additional mechanical part in the camera body. This solution was designed to not only compensate for a uniform compensation to the forward motion but also for angular motion blur and for different scale factors in one and the same image. This is especially important for oblique viewing direction of a camera when foreground and background of an oblique scene definitely shows different scales in one and the same image.

AMC – Adaptive Motion Compensation

The need to compensate for motion blur is evident when large scale aerial imaging is required, and best image quality is expected. Motion blur is caused from the speed of the aircraft over ground, the image scale and an angular component – the angular motion blur - caused from turbulences if they exist.

The magnitude of the forward motion blur can be estimated very easily when multiplying aircraft speed and image scale and exposure time (e.g. speed over ground 75 m/sec, scale 1/10000 and exposure time 0,001 seconds leads to 0,0075 mm or 7,5 µm in the image). Different image scales results in different magnitude of motion blur. This is evident for oblique camera systems. Figure 1 illustrates the situation for an UltraCam Osprey 4.1 flying at a speed of 100 m/sec and at an altitude of about 1065 m above ground level.

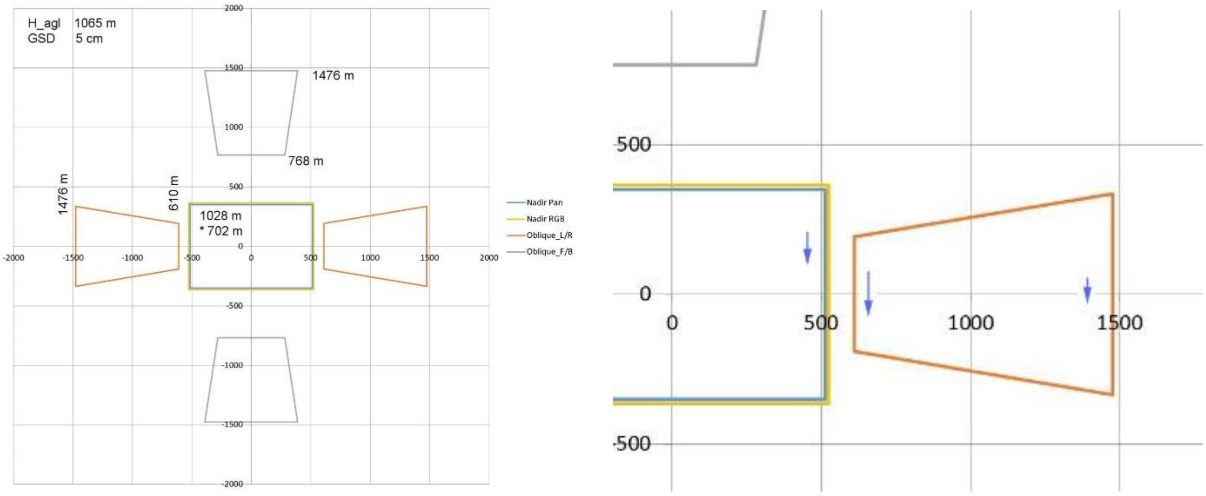

Fig. 1: Magnitude of Image Motion: Left: footprint of UltraCam Osprey 4.1; Right: Motion blur at different image positions
H_agl: 1065 m, Scale Nadir: 1 / 13300, GSD: 5 cm, SOG 100 m/sec, Tv = 1 msec,
Nadir 7,5 µm eq. 2,0 Pixel, Oblique near 10,3 µm eq. 2,76 Pixel, Oblique far 5,9 µm eq. 1,58 Pixel

The magnitude of the angular motion blur depends on the situation in the air, turbulences may happen and cause larger movements of the camera, which cannot be compensated by an active mount. Taking a roll angular rate in consideration, this causes a motion blur perpendicular to the flight line. The magnitude is angular rate multiplied by focal distance and exposure time (e.g. tan (5°) per second multiplied by 80 mm focal length and by 0,001 sec exposure time leads to 7 µm image blur. An example of strong angular motion blur is well visible in Figure 2 and Figure 3.

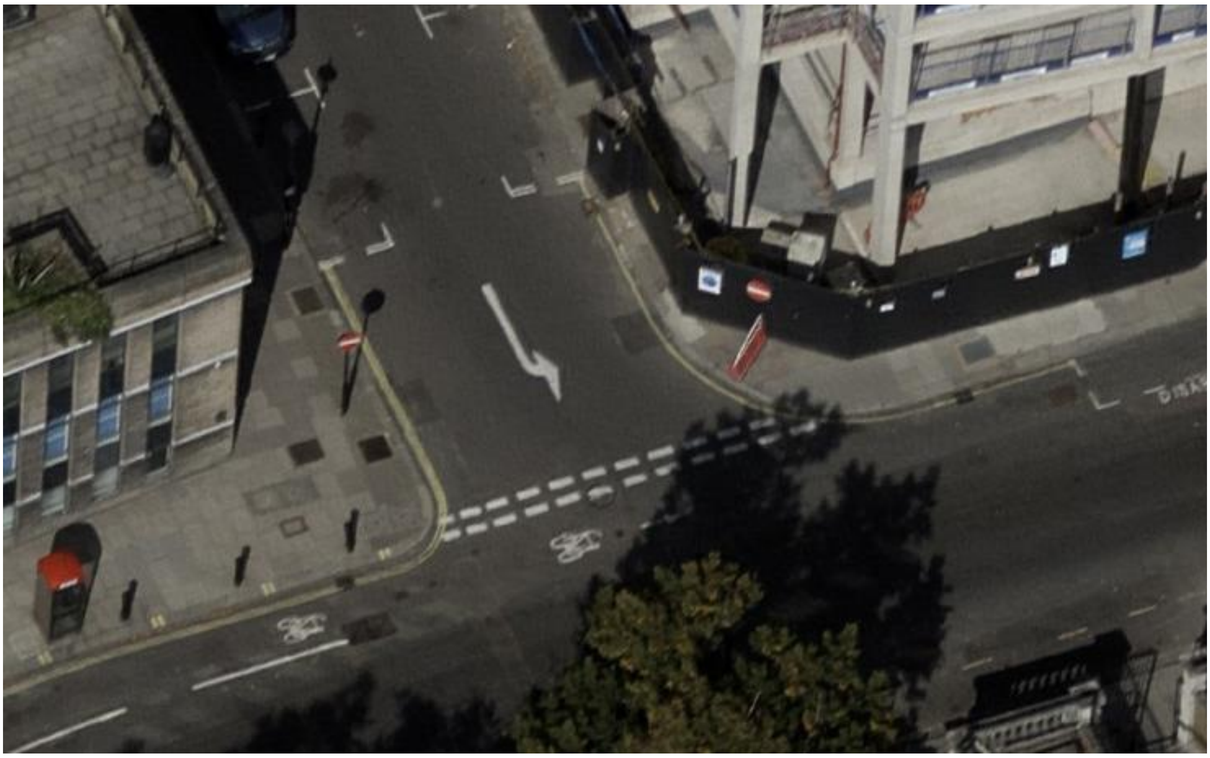

Fig. 2: Oblique backward image of a large-scale flight mission (London, GSD Nadir:3,5 cm). The image has been processed with adaptive motion compensation (AMC) enabled.

Fig. 3: Street details of one large scale oblique image (UltraCam Osprey 4.1, cf. Fig.2). Strong angular motion blur at about 11 pixel exists (cf. left image) and was successfully compensated by AMC (cf. right image)

Mathematical Background

The mathematical background of the Adaptive Motion Compensation technology is the so-called deconvolution or inverse convolution of an image. Knowing the point spread function a good approximation of the deconvolution kernel can be estimated.

The illustration below shows a very simple example. The unblurred image on the left was blurred by a simple motion blur kernel at an angle of 20° from the x-axis. The next image is the result from a deblurring at the proper angle of a motion blur and the image on the right shows the poor result, using a motion blur direction of 110° instead of 20°.

Fig. 4: Illustrating the concept of a deconvolution based on a known PSF. From left to right: original image, blurred image (motion blur at a direction of 20°), restored image making use of the proper PSF and image processed under wrong PSF parameters (blur direction perpendicular to the blur direction).

The example shows that proper settings for the deconvolution is critical and need to be tuned to the optimum to receive good results. The basic solution which is implemented to the AMC procedure does follow this concept. The individual point spread function of each image position is estimated from known angular and translative movements of the camera by making use of IMU and GNSS observations and the effect of the camera system itself is known from calibration.

Benefits of the Adaptive Motion Compensation

The main benefit of AMC is in its software-based solution. There are no mechanical parts which may degrade or cause malfunctions. The second important benefit is the ability of the concept to handle any kind of motion blur, may it be forward motion along the flight path or any other direction, may it be an angular movement of the camera. A third benefit of the AMC solution is its adaptability to the varying magnitude of the blur in the image, depending on the different object scale or image position. This is obvious when oblique images are processed. Foreground and background of such images are different in scale by design. If angular motion blur needs to be removed, the effect of the blur depends on the distance of the image detail to the rotation axis.

Availability of Adaptive Motion Compensation

The AMC technology was developed for Vexcel's UltraCam sensors of the 4th generation and is available through the latest UltraMap Software. The requirements for a proper solution are simple and do not differ from standard modern flight environment. That means the camera management must offer GNSS and IMU recordings to estimate the Point Spread Function and to compute the correct deconvolution kernel.

Example of Adaptive Motion Compensation

A large-scale flight mission by UltraCam Osprey 4.1 at a ground sampling distance of 3.5 cm at the nadir image was used to illustrate the excellent performance of AMC. The nadir image (cf. Figure 5) shows some motion blur due to suboptimal flight conditions. Small structures like tiles on the sidewalk and road markings look unsharp. After applying Adaptive Motion Compensation the image looks sharp and fine structures are visible.

Fig. 5: Street details of one large scale NADIR image (UltraCam Osprey 4.1, GSD nadir 3,5 cm). Motion-blur exist due to suboptimal flight conditions (cf. left image) and was successfully compensated by AMC (cf. right image)

Another example of an oblique image illustrates how effective AMC works against angular motion compensation. The figure below shows building facades, which are blurred due to angular movement of the camera when the image was taken (left side of Figure 6) and the reconstructed image after applying AMC (right side of Figure 6).

Fig. 6: Details of building facades within a large-scale oblique image (UltraCam Osprey 4.1, GSD nadir 3,5 cm). Strong angular motion blur exists (cf. left image) and was successfully compensated by AMC (cf. right image)

Evaluation of a photogrammetric flight mission

We analyze the effect of Adaptive Motion Compensation to a photogrammetric flight mission and compare results of the Aero-Triangulation and the solution of the Bundle Adjustment. This experiment shows how the quality of tie-point-matching, and the overall quality of the bundle adjustment can be improved by AMC (cf. Figure 7 and Table 1).

Fig. 7: Flight mission of UltraCam Osprey 4.1, GSD nadir 5 cm, 304 images (cf. left image). Some forward motion blur exists (cf. right image) and was successfully compensated by AMC (cf. central image)

The Lvl0 data of the flight mission were used to compute a complete aero-triangulation and results were derived from one set with AMC enabled and one set without applying AMC. The results were used to analyze the overall quality of the adjustment by sigma_o and the stability of the camera parameters (Principal Point Position and Focal Distance).

	sigma_o	PPA_x mm	PPA_y mm	FD mm
given		0,000	0,000	79,600
without AMC	0,73	-0,0018	-0,0014	79,6000
with AMC	0,72	-0,0008	-0,0012	79,6001
difference	0,01	-0,0010	-0,0002	-0,0001

Tab. 1: Result of the flight mission without AMC and with AMC applied during the processing. The overall geometric quality is illustrated by sigma_o and improved when applying AMC. The camera parameters were adjusted as well and remained almost unchanged. The maximum difference was detected for PPA_x at a magnitude of 1 µm.

Conclusion

The software based Adaptive Motion Compensation was developed by Vexcel Imaging to improve the quality of UltraCam images and to handle both, forward motion and angular motion. Scale variances across an image are addressed as well. This is significant in the case of oblique images.

We show the benefit of this new method and give examples from a large-scale flight mission. Results from an aero-triangulation and bundle adjustment experiment show the improvement of image measurement quality and the stability of the principal camera parameters.

Literature

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