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IMAGE MOTION COMPENSATION — THE VEXCEL APPROACH

VEXCEL IMAGING

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.

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 altitudeof about 1065 m above ground level.

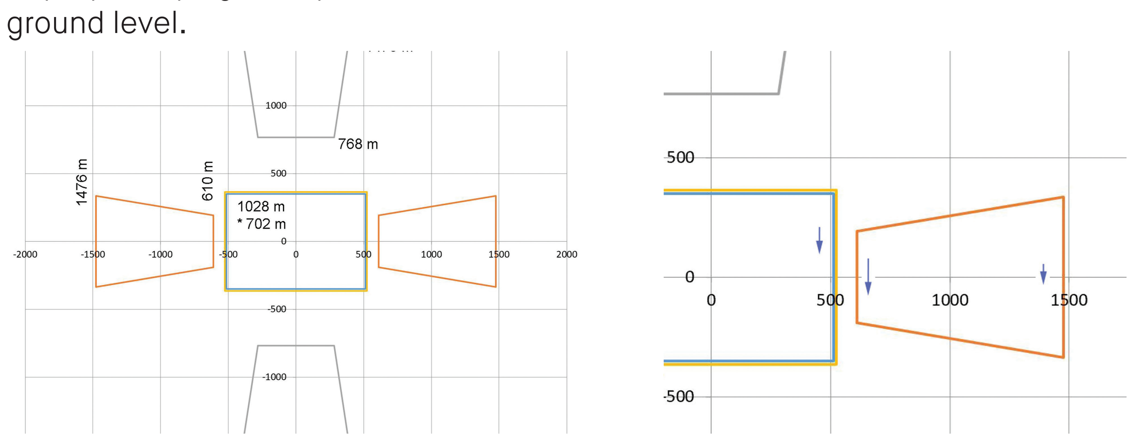

Figure 1: Magnitude of Image Motion:
Left: Footprint of UltraCam Osprey 4.1; Right: Motion blur at different image positionsH_agl: 1065 m, Scale Nadir: 1 / 13300, GSD: 5 cm, SOG 100 m/sec, Tv = 1 msec, Nadir 7,5 µm eq. 2,0 Pixel, Oblique near 10,3 µm eq. 2.76 Pixel, Oblique far 5,9 µm eq. 1,58 Pixel

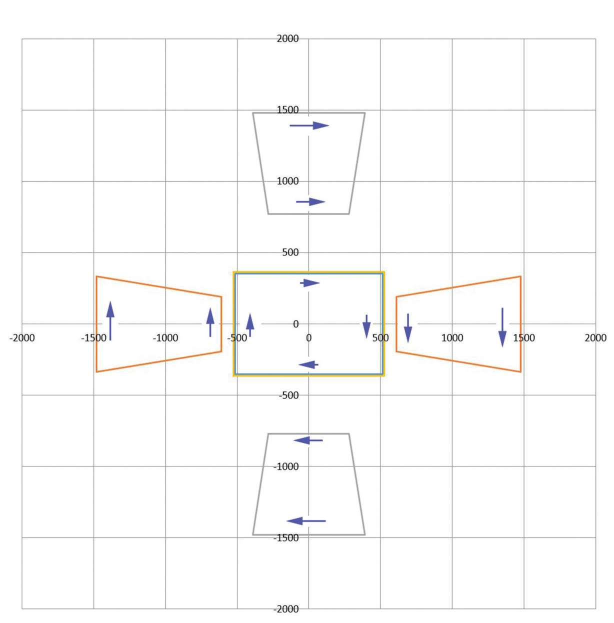

Figure 2: Magnitude of Image Motion:
Angular motion blur (Yaw) at different image positions

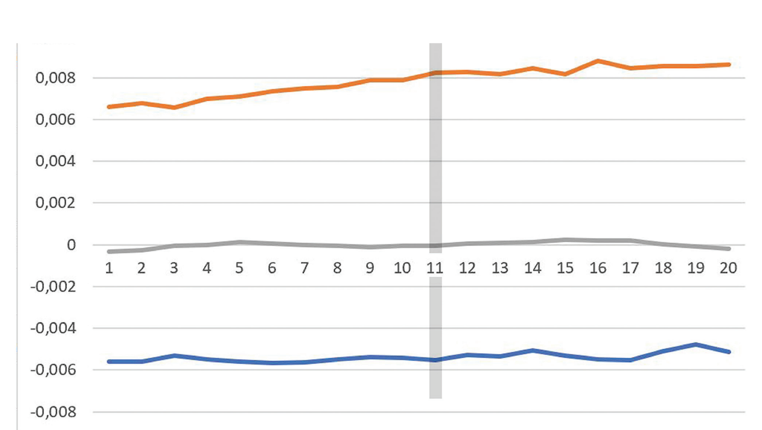

Figure 3: Angular motion of the camera registered from the IMU (# 19103, London, GSD: 3,5 cm). d_omega = -5,5 °/sec, d_phi = 8,2 °/sec, d_kappa = 0,06 °/sec. Read-out interval is 5 msec, the exposure corresponds to position 11.

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 3b.

Figure 3a: Part of large-scale oblique BWD image (# 19103) of a flight mission (London, GSD 3,5 cm). The image has been processed with adaptive motion compensation (AMC).

Figure 3b: Street details of one large scale oblique image (cf. Figure 3 a). Strong angular motion blur at about 11 pixel exists in the raw image data (cf. left image) and this 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. 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

One major 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, such as an angular movement of the camera. Another 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 position to the rotation axis. And finally, a benefit of AMC is the fact that it is a software-based solution. There are no mechanical parts which may degrade or cause malfunctions.

EVALUATION OF A PHOTOGRAMMETRIC FLIGHT MISSION

We analyze the effect of Adaptive Motion Compensation (AMC) 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.

STABILITY OF INTRINSIC PARAMETERS

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 Principal Distance).

The entire block of images contains 304 shot positions. Each shot position includes the mapping grade nadir image and four oblique images. The nadir serves as the photogrammetric backbone of the block and thus it makes sense to analyze results from the aero-triangulation of the nadir image.

	sigma_o	PPA_x mm	PPA_y mm	FD mm
Intrinsic nadir parameters		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

Table 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.

RESULTS FROM EXTERIOR ORIENTATION PARAMETERS

The result of the aerial-triangulation by means of quality parameters of the least squares bundle adjustment were analyzed for three processing scenarios. One and the same set of raw image data (the so-called Lvl0 data) was processed 3 times. For one set no FMC or AMC was enabled for the image processing, the other set contains forward motion compensation only and the final set was processed enabling AMC. It is also noteworthy to mention, that FMC is included in the AMC processing.

RMSE (1/1000 deg)				
Omega	phi	kappa	sigma_o	
7,7	6,9	1,7	0,92	appl. AMC
8,2	7,2	1,7	0,93	appl. FMC
9,0	7,8	1,7	0,94	no corr.
Max Error (1/1000 deg)				
omega	phi	kappa		
19,9	16,0	4,9		appl. AMC
20,9	16,4	5,0		appl. FMC
23,2	17,8	4,9		no corr.

Table 2: RMS and maximum angular residuals from a large-scale dataset (cf. Figure 10) show the improvement of the AMC technology. The maximum difference of 3,3 (1/1000 deg) at omega Max Error corresponds to 1,9 Pixel in the oblique image.

The evaluation of the results from this dataset focuses on overall geometric quality (represented by sigma_o values) and the result of the IMU residuals. Table 2 shows how pose results are improved by correct motion compensation. The quality measures from the roll angle omega are improved by 16% (no correction vs. AMC) and 5% (FMC vs. AMC).

Differences in RMS Residuals in the lateral displacement are small in x and y (below 1%) and slightly larger in the vertical direction 5% larger for FMC compared to AMC and 17% larger when no compensation was applied compared to AMC.

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.

Figure 5: UltraCam Osprey 4.1
The new standard in urban mapping and 3D city modeling

CONCLUSIONS

Excellent image quality is highly desired in photogrammetry. Not only the visual appearance but also the ability to support an accurate photogrammetric workflow is evident. One important attribute of high-quality images is sharpness. This needs to be supported to enable a first-class photogrammetric production. 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. Different scales in the image are considered as well. This is significant in the case of oblique images. We show the benefit of this new method and give examples from large-scale flight missions. Results from aero-triangulation and bundle adjustment experiments show the improvement of image measurement quality. the stability of the principal camera parameters and the improvement of the EO solution.