Forward Motion Compensation (FMC) - Is It the Same in The Digital Imaging World?

by Roger Pacey and Peter Fricker

Where did FMC come from and what is it?

Angular image motion has been affecting image acquisition since the beginning of aerial surveys. All three rotation angles (roll, pitch and yaw) affect image quality. Ideally, Angular Motion Compensation (AMC) in all three angles would solve the problem. Only forward image motion caused by the aircraft's forward movement would remain. In the late 1980s, a way to compensate for forward motion was at last found. The angles of image motion (roll and pitch) were left uncorrected until later when gyro-stabilized mounts controlled by an integrated GPS/IMU systems appeared on the scene.

Forward Motion Compensation (FMC) for Leica aerial film cameras was first made available in 1987 with the Wild RC20. Photography taken with aerial film cameras sold before this date either had to be taken with a short exposure time, which required a fast film of low resolution, or an acceptance of some degree of image blurring in the resulting exposure (especially with photography taken at lower altitudes). This was a result of aircraft movement over the terrain during the time the camera shutter was open. In Leica (Wild) aerial cameras manufactured since 1987, FMC capability compensates for a maximum speed of 64 mm/sec of image movement up to 640 µm at the longest exposure time of 1/100 sec. Figure 1 demonstrates an aerial camera with a six inch focal length lens in an aircraft flying at 100 knots 5250 feet above ground. The shutter speed is 1/200s. These parameters result in photography of 1:10500 scale. Without FMC, this scenario would result in image motion of 25.75 cm (~10 in.) on the ground, or 24 µm in the image plane. As a more extreme example of FMC, there are military aerial reconnaissance film cameras, often installed in low flying military jet aircraft, where the speed of possible film movement for FMC can be as much as one meter per second.

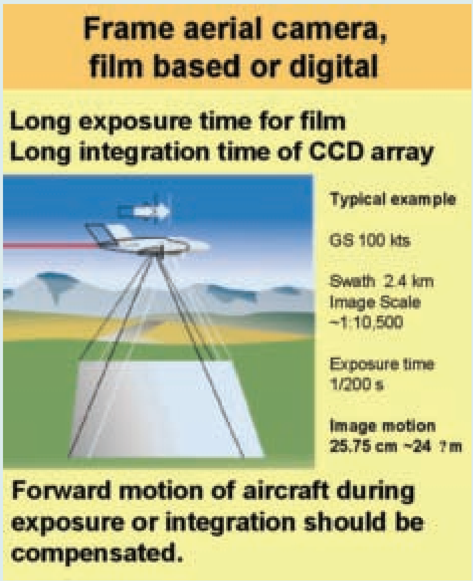

Figure 1.

Film Cameras

In the case of Wild aerial survey cameras, the method of implementing FMC was to move the platen and film a precise amount in the image plane to correspond with the amount of ground distance being traveled by the aircraft during the length of time the shutter was open. In this manner, a point on the ground was being exposed onto exactly the same place on the film during the duration of the exposure. The result of this was a sharper image than was possible before the introduction of FMC. FMC also permitted slower shutter speeds to be used, which in turn enabled the use of finer grain slower speed aerial films. Together these factors resulted in sharper imagery and photo missions that could be flown under poorer lighting conditions than was possible before FMC.

As the first forward motion compensating mechanisms evolved in aerial cameras it became apparent that the other components of angular motion, the so-called lateral image motion as well as fast and random changes of the drift, required compensation too. Once forward motion compensation was addressed, complete angular motion compensation (AMC) could no longer be ignored. Dealing with these motions was only possible with the development of gyro-stabilized mounts. The first generation of such mounts was equipped with internal gyros which could be used as standalone stabilized mounts. Ensuing research showed that stabilization was even better when external information of the flight path and attitude information was used to control the mount. This led to the development of a stabilized mount which is controlled by an external inertial position and attitude system. This system not only keeps the cameras vertically stabilized but also automatically compensates for all short time changes of the drift angle.

The Digital Imaging Scene

Digital Cameras/Sensors

For digital sensors, it was also a requirement that image motion perpendicular to the flight line and changes in the aircraft's drift be addressed adequately. Thus the gyro-stabilized mount controlled by an integrated GPS/IMU became reality. The only thing left to be compensated was forward motion of the aircraft.

There are three ways of limiting the effects of the aircraft's forward motion:

1) using an exposure time shorter or equal to the pixel size
2) mechanically moving the focal plane
3) applying TDI (Time Delayed Integration)

For all three methods to work precisely, exact GS (Ground Speed) and flying height information is required. This could be supplied by a GPS/IMU system.

As described earlier, real FMC as implemented in an analog film camera means that the film must physically be moved to compensate for aircraft movement over ground during the duration of the exposure. In the case of a digital sensor this would mean the Charge-Coupled Device (CCD) must be moved by the FMC device. This would be difficult to achieve with the large format digital framing cameras available today, because the large format is really just a patchwork of images captured by many small format CCD cameras. For real FMC, each small format camera body would require an FMC device. This is not practical for many obvious reasons. For one, these airborne digital framing cameras employ the use of multiple lenses, and have as many

continued on page 1242

continued from page 1241

shutters as lenses in each camera body. Therefore, there are many shutters open for each exposure with these systems, and subsequently FMC would be required for image movement in each of these. The shutters, such as those in some digital frame aerial cameras, have a maximum speed of 1/300 sec. Due to that relatively long exposure time, forward motion needs to be compensated to minimize image smear. The problem becomes how to overcome this without having a real FMC device akin to those used on film cameras.

The patchwork large format framing airborne digital cameras currently in the marketplace employ the TDI technique (Figure 2). TDI is a specialized CCD detector readout mode that is used in applications where there is fast relative movement between the camera and the object being imaged. At the lower flying altitudes where a fast shutter speed is required to limit image smear, the image on the detector is read continuously, one row of pixels at a time from the bottom of the detector chip. As each row is read, the signals in the remaining detector pixels are shifted down by one row causing the latent image to translate down the detector. Therefore, the image smear in one captured image pixel with TDI is never more than that of the Ground Sampling Distance (GSD). During the time the shutter is open and TDI is being used, the airborne platform is in motion. For each successive TDI readout, the airborne platform has a different position, and potentially a different orientation in the air. The accumulative image could be from readouts with differing orientations. Therefore, image smear caused by differing orientations is accumulated in the image.

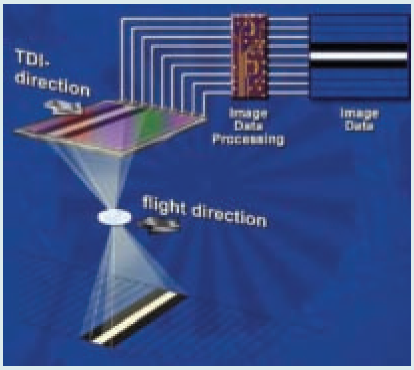

Figure 2.

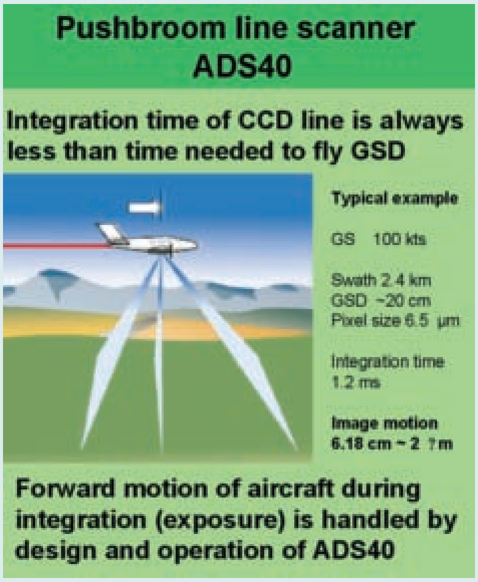

Figure 3.

The Leica ADS40 Airborne Digital Sensor demonstrates one approach to defeating this image smear. The ADS40 operates quite differently from large format digital frame sensor systems. The ADS40 is a CCD line sensor and operates using the "pushbroom" principle. It scans the terrain continually on a flight line. The ADS40 has a single high-resolution telecentric lens in which the readout cycle time of the CCD lines on the single focal plate functions as an electronic shutter. The maximum readout rate of all ten CCD lines in this sensor can be as fast as 1.25 ms (800 Hz). This is significantly shorter than the shutter speeds used in a digital framing camera. The illustration in Figure 3 details the information for the ADS40 when collecting an image swath of 2.4 km at a GSD of 20 cm. This equates to identical coverage with a film based or digital framing system as depicted in Figure 1. As the diagram shows, the amount of pixel smear is about one third of the collected GSD. The result is that with sensors such as the ADS40, all image motion handling is inherent in the design.

Figure 4.

The ADS40 is capable of handling image motion even at GSDs suitable for engineering scale photogrammetry. As an example, an ADS40 was flown in 2004 over the University of Stuttgart, Institut für Photogrammetrie (IFP) test field at Vaihingen/Enz in Germany, producing panchromatic imagery at a GSD of 5 cm (see Fig. 4). This is similar to that captured with large format frame cameras at this GSD, which also collect in panchromatic mode directly at this resolution.

Conclusion

FMC, as implemented in an analog aerial camera, involves physical movement of the film. With a digital camera/sensor, no such physical action takes place. The requirement to handle image motion with a digital system is either handled by additional capability provided by the CCD detector, namely TDI, or by the overall design of the system. A digital frame sensor with TDI limits forward image smear to one pixel, as is the case in pushbroom scanners like the Leica ADS40. Additionally, a TDI frame sensor may run the danger of having image smear caused by lateral motion and drift of the sensor during accumulated image capture.

Several government agencies around the world have realized that the methods for calibrating analog aerial cameras are not applicable to the new digital cameras/sensors, and have certified newer methods of calibration. This supports the growing opinion in the marketplace that TDI is not FMC as we know it - from the analog camera - nor for that matter is FMC equivalent to TDI. With the advent of airborne digital imagery, the photogrammetric industry and contracting agencies are rethinking FMC, embracing new technology, standards and specifications.

Authors

Peter Fricker, Product Manager, ALDS40, Leica Geosystems Geospatial Imaging, Peter.Fricker@gi.leica-geosystems.com

Roger Pacey, Leica Geosystems Geospatial Imaging, until he passed away earlier this year