

## DIRECT PLATFORM ORIENTATION OF MULTISENSOR DATA ACQUISITION SYSTEMS

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Commission IV

**KEY WORDS:** Sensor Integration, Digital Imaging Sensors, GPS, INS, Airborne Mapping

### ABSTRACT

With increased use of various new sensors in mapping such as digital cameras, multi/hyperspectral scanners, radiometers, LIDAR, SAR (IFSAR), etc; multisensor data fusion has become an extremely crucial task of spatial data processing. One of the key aspects of integrating various data types is data geo-referencing. Direct platform orientation provides an efficient tool for geo-referencing at the data acquisition level, by substantially supporting the multisensor data integration process through furnishing a common geo-coding frame at a very early point.

The Airborne Integrated Mapping System (AIMS™) developed at The Center for Mapping at The Ohio State University offers GPS/INS-based integrated direct platform orientation. Currently, the imaging component of the AIMS™ prototype system is based on a high-resolution Charge-Coupled Device (CCD), a solid-state image sensor capturing 4K by 4K panchromatic imagery. In cooperation with AIMS™ partners, however, laser and multi/hyper spectral sensors have been also included in a series of test flights. This paper investigates the performance of the AIMS™ GPS/INS orientation module as well as the data fusion experiences obtained from various sensor data.

### 1. INTRODUCTION

Recent rapid technological developments have created revolutionary new methods to acquire and process spatial data. The variety of systems for 3D data acquisition, processing and visualization has dramatically increased in recent years. On the spatial data acquisition side, one can find a plethora of new sensors as well as integrated GPS/INS-based direct orientation systems (Lithopoulos, 1996; Schwarz, 1995). In fact, these new platform orientation systems are rapidly emerging as a core component of modern airborne mapping and remote sensing systems.

The Center for Mapping at The Ohio State University has developed a GSP/INS integrated positioning system to support primarily digital sensor-based image data collection for the Airborne Integrated Mapping System. The AIMS™ project goal is to acquire position and orientation of an aerial platform with accuracy of 4-7 centimeters and below 10 arcsec, respectively, over long baselines, which will eliminate the need for ground control. Positioning and orientation accuracies should allow for post-processing of digital imagery to extract feature coordinates at submeter accuracy.

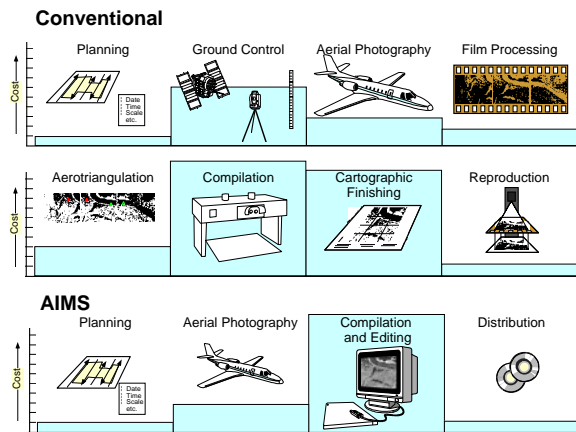
### 2. AIRBORNE INTEGRATED MAPPING SYSTEM

The Center for Mapping has always been a pioneer in researching and developing new mapping technologies

since its inception in the late 80's. The idea of the AIMS™ project (Bossler, 1996) surfaced shortly after the commercialization process of the GPSVan™ (Bossler and Toth, 1996; Novak and Bossler, 1995) had been successfully completed in 1995. The first year of the AIMS™ project started with establishing the necessary partnerships with key technology providers as well as with other organizations involved in state-of-the-art mapping (Bossler, 1996). Algorithmic research, systems design, identifying potential imaging technologies and software developments as well as simulations characterized the first project year (Da, 1997, Grejner-Brzezinska, 1998). The arrival of the AIMS™ positioning component in early 1997 signaled the beginning of the test flights (Toth, 1997). The complete, 4K by 4K CCD-based digital camera-equipped AIMS™ prototype has been flown since the end of 1997 (Toth, 1998).

The AIMS™ system concept is built around two principal ideas: direct orientation of the airborne platform and the promotion of electronic imaging. The direct determination of the platform position and orientation is essential for many new non-conventional imaging sensors but is certainly helpful for conventional aerial surveys too. The primary benefits of the direct digital image acquisition are the substantially reduced processing time, elimination of scanning, and potential for real-time functions. Figure 1 represents the AIMS™ concept for the most common aerial surveying application.

### A Comparison of Mapping Scenarios



**Figure 1.** AIMS™ vs. traditional mapping.

The AIMS™ positioning component currently comprises two dual-frequency Trimble 4000SSI GPS receivers and a medium-accuracy and high reliability strapdown Litton LN-100 inertial navigation system, based on Zero-lock™ Laser Gyro (ZLG™) and A-4 accelerometer triad (0.8 nmi/h CEP, gyro bias – 0.003°/h, accelerometer bias – 25µg). The LN100 firmware, modified for the AIMS™ project, allows for access to the raw IMU data, updated at 256Hz (Litton Systems, 1994). Figure 2 shows the LN100 system installed in an aircraft. Estimation of errors in position, velocity, and attitude, as well as errors in inertial and GPS measurements is accomplished by a centralized Kalman filter that processes GPS L1/L2 phase observables in double-differenced mode together with the INS strapdown navigation solution (Da, 1997; Grejner-Brzezinska, 1997).



**Figure 2.** LN100 INS installed in an aircraft.

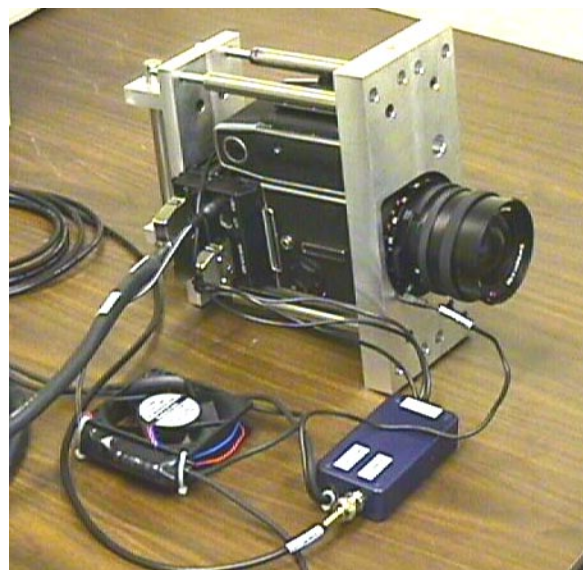
The heart of the 4K by 4K AIMS™ High-Resolution Digital Camera System is a 4K by 4K area CCD sensor with 15-micron pitch (i.e. 60 mm by 60 mm imaging area), manufactured by Lockheed Martin Fairchild Semiconductors. The sensor assembly, shown in Figure 3, is marketed under the name of BigShot™. The imaging sensor with supporting data acquisition

interface is integrated into a camera-back, mechanically compatible with an analog film magazine, and thus, attaches easily to a regular Hasselblad camera body.



**Figure 3.** 4K by 4K BigShot™ camera-back.

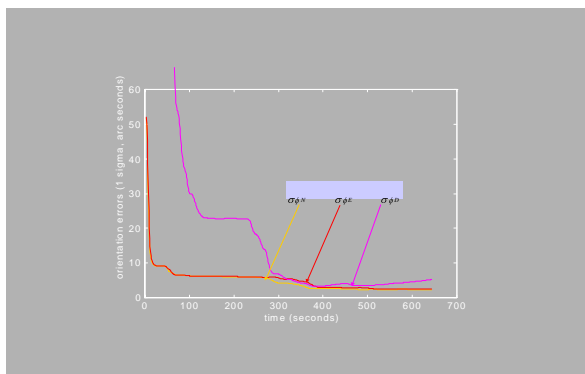
The Hasselblad 553 ELX camera body features an electronic control system providing the necessary apparatus for a fully digital – computer-controlled – camera operation. Zeiss CF lenses with 50 mm and 80 mm focal lengths supplement the experimental camera system, offering both wide and normal angle configurations. Building the 4K by 4K AIMS™ digital camera and data acquisition system around the BigShot camera-back equipped Hasselblad camera involved several hardware and software subtasks (Toth, 1998). The most recent pressure mount is shown in Figure 4.



**Figure 4.** 4K by 4K AIMS™ camera pressure mount.

### 3. AIMS™ PERFORMANCE

The AIMS™ error budget is formed from the independent error budgets of the positioning and imaging components. The performance of the GPS/INS AIMS™ positioning module has been repeatedly checked at different phases of the development process, and those first road and later flight tests have shown very favorable results. In order to compare AIMS performance with existing aerial surveying methods, test flights were organized in cooperation with several AIMS Associate Partners. These experiments were intended to match AIMS performance against traditional aerial-triangulation techniques. Since the GPS-only positioning accuracy has been known for years, the real questions were whether the use of the INS could improve this position data and what the accuracy of the attitude data would be. Because the developed Kalman-filter estimates the different error terms, the internal accuracy of the positioning system is easily available. Figure 5 shows better than 10 arcsec attitude accuracy for typical cases.



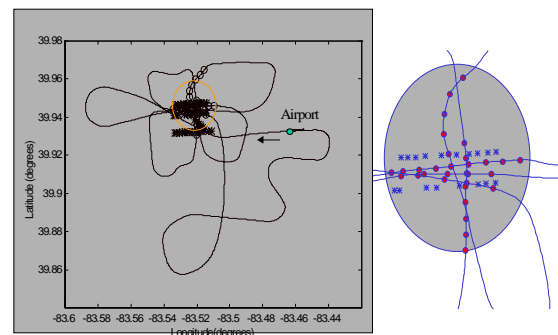
**Figure 5.** Internal accuracy of the AIMS™ positioning component.



**Figure 6.** Madison calibration range image.

The performance analysis of the imaging component is concerned only with the 4K by 4K AIMS™ digital camera prototype. Figure 6 shows the Madison calibration range used in many airborne sensor calibrations. Figure 7 depicts the flight trajectory of the first AIMS™ flight with a 4K by 4K camera over the test range.

Due to the unusually high lens distortion of the AIMS™ camera (as compared to the quality of large-format aerial camera lenses) and the flat terrain of the test range, in-flight camera calibration was not feasible. Therefore, an indoor calibration range was built. Over a 5 by 5 m area, approximately 200 targets were laid down in a regular grid pattern. The targets, shown in Figure 8, were coded to support automatic target recognition.



**Figure 7.** Flight trajectory of the first full-blown AIMS™ prototype flight.

The indoor calibration range is normally imaged from eight different positions with substantial depth range. The target points were surveyed by traditional methods. The image measurements were performed on an Autometric SoftPlotter digital photogrammetric workstation. The raw image coordinates were exported from the softcopy system. There have been three software packages used for calibration: 1) Bundle with Self-Calibration (BSC) from OSU in a UNIX environment, 2) a newer, PC NT-based version of BSC, and 3) XCALT from TopoPhoto on DOS PC platform. The results were basically identical for the two versions of the BSC program. There was some minor difference between the BSC and XCALT solutions. The discrepancy was mainly in scaling, and the visualized lens distortion surfaces showed a good match. Figure 9 shows the calibration results and surface for the 50 mm lens. The USGS camera calibration model was used during the consecutive photogrammetric data reduction.

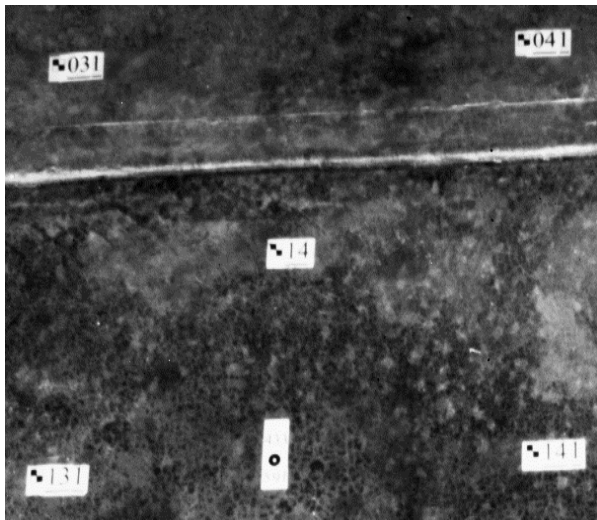


Figure 8. Indoor calibration range targets.

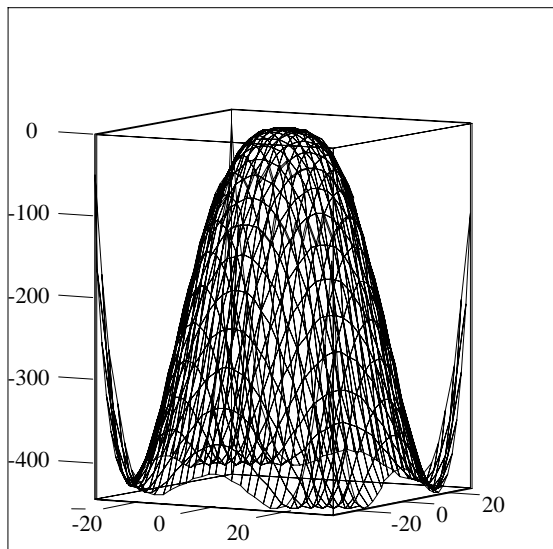


Figure 9. Lens distortion surface of the 4K by 4K AIMS™ camera.

Based on the camera calibration data, aerial-triangulation was performed for a small block to determine the exterior orientation of the images for the boresight calibration. The difference between the photogrammetric data and the GPS/INS-derived data defines the boresighting transformation, which has offset and rotation components. The offset between the INS origin and the camera projection center is less critical and can be computed quite easily. In fact, the term “boresighting” usually refers only to the rotation component. The angular inaccuracy, unlike the offset, is amplified by object distance and has a significant impact on the photogrammetric data extraction. Models set by the aerotriangulation showed model parallax around 5 microns, representing one third of a pixel, while the GPS/INS derived models showed parallax in

the 15 micron range. The reason for this discrepancy has yet to be seen. Table 1 shows the projection center data differences between aerial-triangulation derived and GPS/INS provided data. The results were obtained from the recent Florida test flight on June 4, 1998.

Image ID	dX	dY	dZ	dκ	dφ	Dω
	[m]	[m]	[m]	[deg]	[deg]	[deg]
36242	-0.251	-0.141	0.028	0.0303	-0.0835	0.0115
36248	-0.340	0.239	0.052	-0.0121	-0.1277	-0.0647
36254	0.314	0.404	0.163	-0.0235	0.0450	0.0199
36614	-0.057	-0.026	-0.054	0.0252	-0.0210	-0.0151
36620	-0.234	-0.012	-0.019	0.0141	0.0725	0.0586
36626	0.197	0.152	0.154	-0.0657	0.0537	-0.0003
37020	-0.068	-0.010	0.069	0.0240	0.0288	0.0444
37026	-0.096	0.384	0.246	0.0238	-0.0069	-0.0277
37032	0.306	0.032	0.270	-0.0159	0.0289	0.0226
37419	-0.304	-0.217	0.107	0.0097	-0.0085	0.0257
37425	-0.264	0.017	0.119	0.0402	-0.0094	0.0078
37431	0.517	0.424	0.055	-0.0563	0.1384	-0.0513
37838	-0.117	-0.227	0.003	0.0233	0.0022	0.0622
37844	-0.284	-0.013	0.007	0.0075	-0.0025	-0.0249
37850	0.298	0.261	-0.045	-0.0245	0.0862	-0.0987
38274	-0.243	-0.071	0.016	0.0133	-0.0102	-0.0304
38280	-0.075	0.144	-0.005	0.0091	0.0220	0.0094
38286	0.062	0.388	-0.362	-0.0302	0.0604	-0.0854
Mean	-0.035	0.096	0.045	-0.0004	0.0149	-0.0075

Table 1. Difference between projection center data, conventional photogrammetric vs. AIMS™ technique.

#### 4. AIMS™ EXPERIENCES WITH VARIOUS IMAGING SENSORS

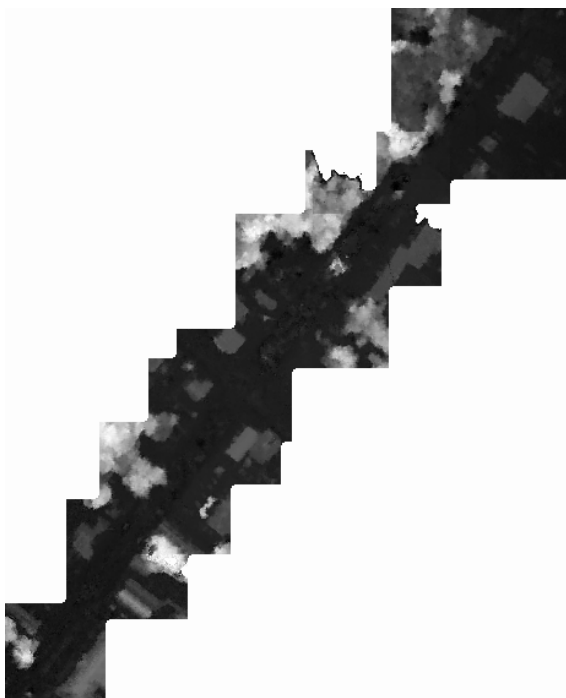
After several test flights with various AIMS hardware configurations, a laser scanner system and a hyperspectral digital camera were included in the two most recent AIMS flight missions.

A pilot project, organized by the University of Florida in cooperation with several other participants, was intended to exploit the potential of emerging new mapping technologies for high-resolution, accurate spatial data acquisition to extract high resolution surface data over transportation structures. Apart from traditional aerial surveying technique, a laser scanner was the central part of this test. As another new competing method, large-scale AIMS™ imagery was used to deliver high-accuracy DEM produced in a softcopy environment. The instrumentation on the aircraft provided by the Florida Department of Transportation included the complete AIMS™ hardware prototype and a special INS/CCD mount fabricated for the project. A special flying pattern had to be used to resolve the conflict between the high image acquisition rate (1.5 sec) and the limited camera cycling time (6 sec). The project area was divided into smaller segments. These shorter segments were flown in several passes with phased image capture (to provide sufficient margin, six passes were organized with 1-sec delayed image acquisition). Figure 10 shows the central project area.



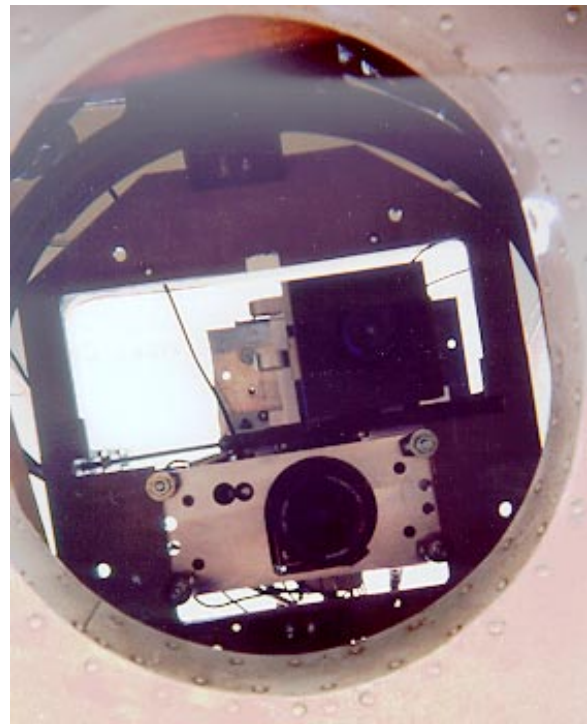
**Figure 10.** Typical AIMS™ image from the Callahan, FL area.

The data processing included several steps such as camera calibration (a posteriori laboratory calibration), boresighting calibration (by using control points from a small area), GPS time-tag vs. image file matching, exterior orientation (EO) extraction from GPS/INS for given time-tags, and image preprocessing. DEMs were obtained on a SoftPlotter system. The elevation modulated intensity image is shown in Figure 11. Note the problems caused by moving traffic.



**Figure 11.** DEM image mosaic over the Callahan, FL.

In cooperation with NASA Stennis Space Center, a hyperpsectral scanner (Mao and Gress, 1998) was flown with AIMS™ recently. The importance of direct platform orientation is great for such pushbroom types of sensors, since without overlapped imagery, geo-referencing is rather difficult. Figure 12 shows the camera assembly through the camera hole of the aircraft.



**Figure 12.** Hyperspectral system and AIMS™ camera installation.



**Figure 13.** 4K by 4K AIMS™ image of space resolution target range at NASA Stennis Space Center.

The short time before the submission deadline for this paper did not allow for complete data processing and analysis of this hyperspectral data. Figure 13 shows an AIMS image taken over the space target range at the Stennis space test site.

## 6. CONCLUSION

The hardware/software prototype of the AIMS™ system has shown consistent performance in a large number of test flights. The accuracy of the positioning system has been repeatedly confirmed both by internal estimation and by external validation using photogrammetric technique. The performance of the 4K by 4K AIMS™ camera has shown gradual progress since its introduction in late 1997. Although the visual quality has been excellent from the beginning, the mechanical stability of the camera has been only improved substantially by using pressure mount. Since then, camera calibration and boresighting have shown consistent results, proving that high-resolution spatial data can be obtained from the AIMS™ digital camera system. Recent tests with various imaging sensors such as laser scanners and hyperspectral cameras are very encouraging. Using the AIMS™ positioning component offers better geo-referencing, substantial cost reduction in processing, and much shorter turnaround time. Obviously, direct platform orientation will become a core component of any new state-of-the-art airborne mapping and remote sensing systems.

## ACKNOWLEDGEMENTS

This work was supported by the NASA Stennis Space Center, MS, Commercial Remote Sensing Program grant #NAG13-42, and a grant from Litton Systems, Inc.

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