

Innovations to Increase Productivity of Airborne Sensors

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ABSTRACT

Since the 2001 ADS40 introduction, more than 30 are in use worldwide producing digital large format imagery and image strips in great quantities. This pioneering step generated great interest within the geospatial community who anticipated promising return on investment results. This report highlights several productivity increasing developments of the ADS40's initial years in the market. It also describes other planned innovations that will further increase ADS40 productivity.

1. INTRODUCTION

With the first commercial sale of the ADS40, the attention immediately focused on its return on investment. The large urban orthophoto projects in Japan were so successful, the ADS40 owner ended up buying three units to satisfy the need for this type of imagery. In the USA, the USDA's National Agriculture Imaging Program (NAIP) verified that ADS40 imagery could bring the cost of multi-spectral 1m GSD imagery down to 14 USD per square mile, not achievable with satellite imagery. Additionally, the ADS40 proved its rapid deployment capabilities for Australian Defense by providing 20cm fly-through imagery from areas without ground control within 7 hours of the aerial mission. There was no doubt that the ADS40 had opened up new possibilities of speed and cost reduction that before were unthinkable.

2. EXPERIENCE WITH THE NEW FOCAL PLANE

The large demand in the USA for large area coverage RGB and FCIR images and orthophotos inspired Leica to adapt the focal plate of the ADS40 to the wishes of customers. This new focal plate has the RGB lines together with the Trichroid (co-registration device) at Nadir instead of in the half-forward position. Additionally, the half-forward position was populated with an RGNir triplet, which made the production of medium to small scale FCIR orthophoto production more efficient.

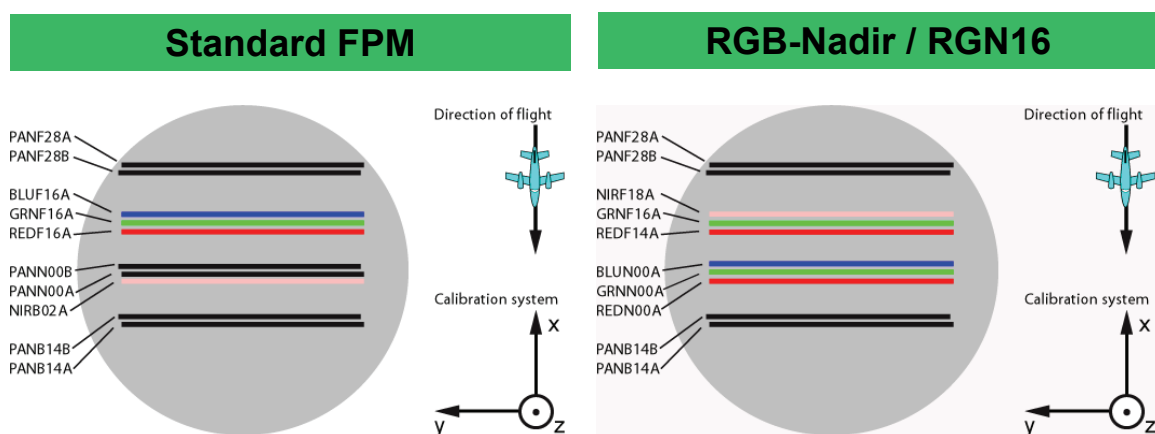


Figure 1: Standard focal plate and new focal plate with RGB/Nadir and RGN/16.

This shows how flexible the line sensor concept is for adaptability to customer needs and also to technological changes. To date, a total of four different focal plate arrangements exist of which the two not shown are specially customized versions.

3. 5CM ADS40 IMAGERY FOR LARGE SCALE MAPPING

It was the aim of ADS40 development to deliver an airborne digital sensor that would provide images for stereo-compilation with the same accuracy as film-based digitized images from the RC30 aerial camera. The focal plate of the ADS40 is only about half as large as that of an RC30 film negative. This theoretically should result in a lower measuring accuracy. Instead, the totally digital workflow proved to compensate fully for this difference. The accuracy reducing influence of uneven film shrinkage, few fiducials, chemical development of the film, fast drying of the film and, last but not least, digitizing the developed film are all not present in the all-digital workflow. The first certification processes have proved this and the ensuing verification tests over Waldkirch and Vaihingen/Enz left no doubt that the original goal had been achieved.



Figure 2: 3D perspective of the Vaihingen/Enz test field of the University of Stuttgart.

Tests were flown over Vaihingen/Enz at flying heights of 500m, 1500m, 2500m and 4000m. The test results will be published separately. For the most common case of 15cm GSD using an LN200 Inertial Measurement Unit, the results in Figure 3 were obtained.

Case	Accuracy	Δ East [m]	Δ North [m]	Δ Vertical [m]
Case 1 12 GCP 190 ChP	RMS	0.052	0.054	0.077
	Mean	0.000	-0.022	0.045
	Std.Dev.	0.052	0.05	0.063
	Max. Dev.	0.133	0.188	0.242
Case	Accuracy	Δ East [m]	Δ North [m]	Δ Vertical [m]
Case 2 4 GCP 198 ChP	RMS	0.055	0.054	0.106
	Mean	-0.008	-0.008	0.083
	Std.Dev.	0.055	0.053	0.065
	Max. Dev.	0.145	0.191	0.295
Case	Accuracy	Δ East [m]	Δ North [m]	Δ Vertical [m]
Case 3 0 GCP 202 ChP	RMS	0.11	0.086	0.158
	Mean	0.094	-0.064	0.142
	Std.Dev.	0.057	0.056	0.068
	Max. Dev.	0.242	0.256	0.351

Figure 3: Vaihingen/Enz, 15cm GSD test, absolute object space accuracy, flying height 1500m.

Most ADS40 users required ground resolution in the 15cm to 40cm GSD range. The determination of the accuracy at 5cm GSD was proven much later after some competitors claimed the ADS40 could not achieve such a small GSD. The 5cm GSD images flown over Vaihingen/Enz in June 2004 proved to be of extraordinarily good quality. Objects smaller than the 5cm, such as high-voltage transmission lines, could easily be seen.



Figure 4: Vaihingen/Enz, panchromatic image, 5cm GSD, flying height 500m.

The results of the 5cm GSD tests over Vaihingen/Enz proved that the ADS40's accuracy was better than originally expected. Height measurement results from different flying heights over the Vaihingen/Enz test field of the University of Stuttgart indicated that the stereo-metric height measuring accuracy of the ADS40 imagery had actually improved from the normally assumed height accuracy of 0.1‰ of flying height for film-based imagery to 0.05‰ of the flying height for ADS40 stereo imagery. [Figure 5]

Case	Accuracy	Δ East [m]	Δ North [m]	Δ Vertical [m]
Case 1 12 GCP 68 ChP	RMS	0.064	0.047	0.035
	Mean	-0.006	-0.009	-0.012
	Std.Dev.	0.064	0.047	0.033
	Max. Dev.	0.246	0.177	0.093
Case	Accuracy	Δ East [m]	Δ North [m]	Δ Vertical [m]
Case 2 4 GCP 76 ChP	RMS	0.064	0.047	0.106
	Mean	-0.013	-0.002	0.083
	Std.Dev.	0.063	0.047	0.065
	Max. Dev.	0.237	0.172	0.1
Case	Accuracy	Δ East [m]	Δ North [m]	Δ Vertical [m]
Case 3 0 GCP 80 ChP	RMS	0.065	0.07	0.042
	Mean	0.03	-0.054	0.019
	Std.Dev.	0.057	0.045	0.037
	Max. Dev.	0.301	0.224	0.112

Figure 5: Vaihingen/Enz, 5cm GSD test, absolute object space accuracy, flying height 500m.

At the beginning of the airborne digital sensor era, many film-oriented photogrammetrists had difficulty relating to the terminology and the rules of thumb used in direct digital workflows. It was necessary for them to overcome the limitations imposed on their map scaling concepts that were

tied to image scales. The term “image scale” was already a fuzzy ratio in film-based applications. Lens cones of different focal length and films of different quality were being used, disturbing the image scale concept. In the case of digitally acquired images using CCD’s with varying pixel dimensions, the image scale can no longer be used as a comparative parameter. For digitally acquired images, the ratio of GSD to map scale is relevant. This ratio has proven its worth over many years in the satellite imagery world and can be used as well in digital photogrammetry. Using this ratio is even more appropriate for digital workflows where output on screens and printers is defined relative to pixel size.

Results from worldwide user cases and research conducted by the University of Stuttgart over the Vaihingen/Enz test field led to the publication of the table below [Figure 6]. This table likely is overly conservative and will be amended as more experience is gained.

Average GSD with ADS40	Map Scale	Map standard		Comparable film photographs	
		x-y accuracy RMSE	contour interval	photo scale	pixel size on on ground of scanned film
5 - 10 cm	1 : 500	0.125 m	0.25 m	1 : 3,000 to 1 : 5,500	2.5 - 5 cm
10 - 15 cm	1 : 1,000	0.25 m	0.5 m	1 : 5,000 to 1 : 8,000	5 - 7.5 cm
15 - 20 cm	1 : 1,500	0.40 m	0.75 m	1 : 6,500 to 1 : 10,000	7.5 - 10 cm
20 - 30 cm	1 : 2,000	0.50 m	1 m	1 : 8,000 to 1 : 11,000	10 - 15 cm
25 - 35 cm	1 : 2,500	0.60 m	1.25 m	1 : 8,500 to 1 : 13,000	12.5 - 17.5 cm
30 - 50 cm	1 : 5,000	1.25 m	2.5 m	1 : 12,000 to 1 : 18,000	15 - 25 cm
40 - 60 cm	1 : 10,000	2.50 m	5 m	1 : 17,000 to 1 : 27,000	20 - 30 cm
50 - 70 cm	1 : 20,000	5.00 m	10 m	1 : 25,000 to 1 : 35,000	25 - 35 cm
50 - 80 cm	1 : 25,000	6.25 m	12.5 m	1 : 28,000 to 1 : 42,000	25 - 40 cm
50 - 100 cm	1 : 50,000	12.5 m	20 m	1 : 40,000 to 1 : 60,000	25 - 50 cm
50 - 100 cm	1 : 100,000	25 m	50 m	1 : 60,000 to 1 : 90,000	25 - 50 cm

Figure 6: GSD to map scale accuracy table.

4. GPRO/LPS WORKFLOW

For four years, Leica GPro Software has been the link between ADS40 data stored in mass memory to a variety of digital photogrammetric workstation and workflows. With the introduction of the Leica Photogrammetry Suite (LPS), a digital workflow for photogrammetric applications is now available. These Leica developed software modules include feature extraction with Pro600 and terrain extraction. Practical experience with LPS and Pro600 has shown that feature extraction from stereo strip images is extremely fast and efficient due to the quasi-orthogonal characteristics of ADS40 images. With frame-based stereo images, constantly varying stereo angles and viewing angles create the stereo impression. ADS40 stereo strip images create a stereo impression from a pair of images which were formed from a constant stereo angle and from constant viewing angles. This consistency throughout the entire stereo strip model allows the stereo operator to work with less stress and more viewing comfort. Manual point and line extraction from ADS40 stereo strip imagery is very well accepted by operators.



Figure 7: Part of a 10km long, 20cm GSD stereo pixel carpet with constant stereo angle and viewing angle.

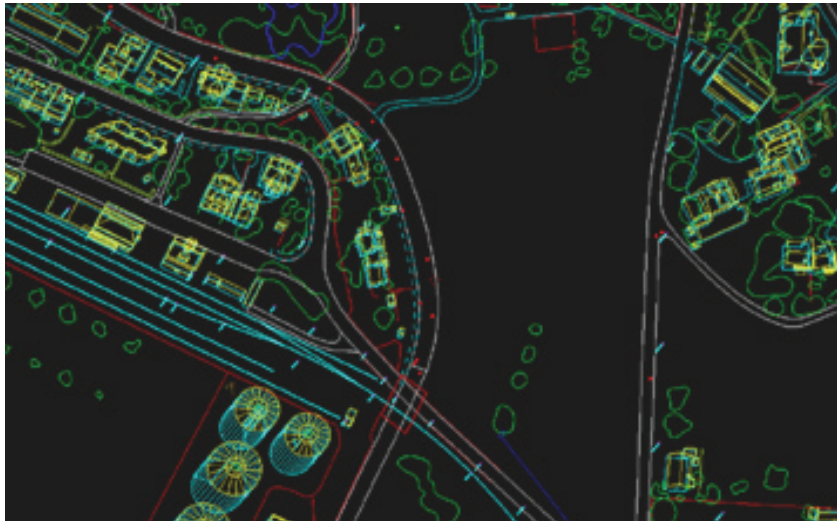


Figure 8: Feature extraction from Figure 7 with Leica Photogrammetry Suite (LPS) and PRO600.

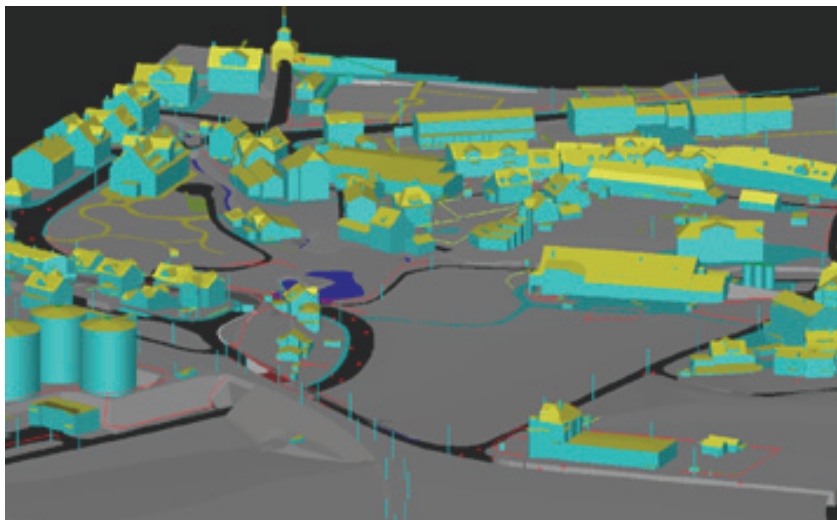


Figure 9: Rapid generation of 3D perspective image based on LPS feature extraction of Figure 8

5. ONGOING RESEARCH AND DEVELOPMENT

5.1. FPES

The new Leica Flight Planning and Evaluation Software (FPES) was announced at ASPRS in April 2005 and will have a fall 2005 release. In line with Leica's strategy to offer a complete workflow from one supplier, this module constitutes the first step in the geospatial imaging workflow. FPES provides a seamless data flow from flight planning to all photogrammetric applications. The main benefit of FPES is that flight planning, proposals, flight reporting and invoicing can be generated from the same tool. FPES blends with the needs of either Aerial Survey Control Tool (ASCOT) or Flight Control and Management System (FCMS) users and can be used on all types of geographic and grid systems. This will allow efficient flight planning for all types of sensors including RC30, ADS40, ALS50 and other frame, line or ON/OFF sensors.

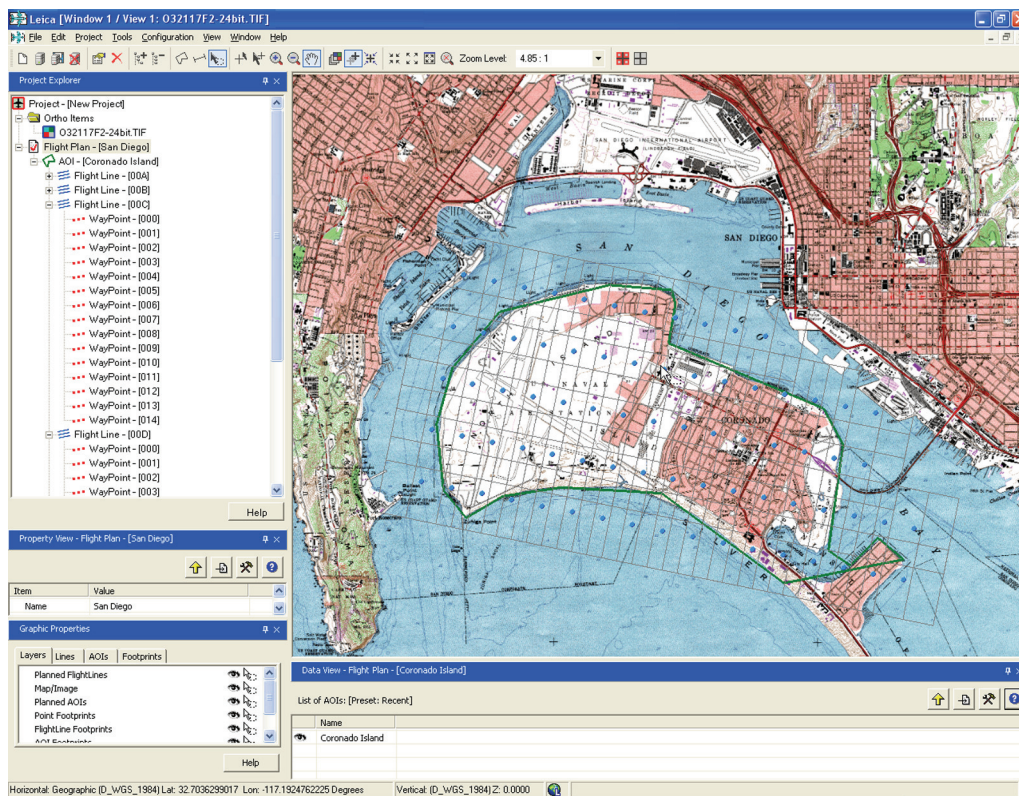


Figure 10: Screen shot from the new Flight Planning and Evaluation Software (FPES).

5.2. FCMS v2.0

The ASCOT system, well known from the RC30 environment, has also been used for the ADS40 survey flight execution. With the new version of the ADS40 Flight and Control Management System (FCMS) v2.0, it will not be necessary to have an ASCOT system on board the aircraft. The flight plan established with FPES described above can be introduced directly into the FCMS of the ADS40. The survey flight will be executed directly from the Operator Interface OI40 of the ADS40. For the pilot, there are two alternative flight guidance displays; the simple LED display GI40 [Figure 12] and the screen-based display OC50 [Figure 13].

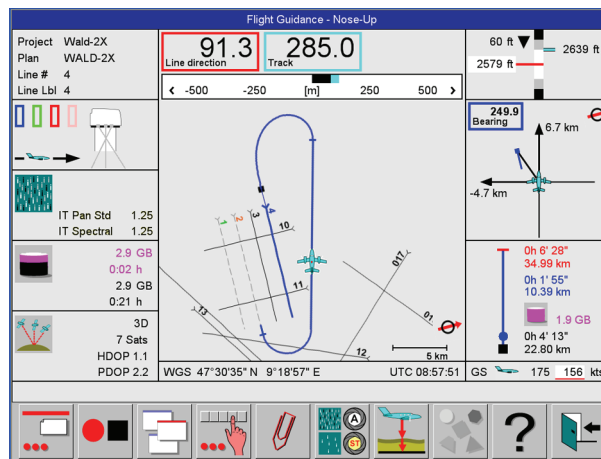


Figure 11: Screen shot from the new Flight Control Management Software (FCMS).



Figure 12: Aircraft dashboard pilot guidance indicator GI40 for FCMS v2.0.



Figure 13: Pilot operation controller OC50 for FCMS v2.0.

6. ACQUISITION OF GPS/IMU TECHNOLOGY

From the outset of ADS40 development, any new technology was to be so well integrated that the operator would not have to deal with additional complexity during flight. This integration aim simultaneously sought reductions in weight and space requirements. Integrating third party products complied with this objective and the GPS/IMU POS system from Applanix was chosen. When Applanix was acquired by one of Leica Geosystems' direct competitors, a decision was made to develop an independent solution. In the beginning of 2005, Leica acquired the technology of a Calgary, Canada company, Terramatics and a new GPS/IMU system from Leica Geosystems was

conceived. This new system, the Inertial Position and Attitude System (IPAS) includes advanced components also selected to ease export licensing restrictions.



Figure 14: Leica IPAS10 GPS/IMU flight trajectory sensor unit, standalone version.

This new system will initially be integrated with the Leica Airborne Digital Sensor ADS40 and, in its standalone configuration, with the Leica Airborne Laser Scanner (LIDAR) ALS50. In the future, it will also become available for use with an RC30 and for other third-party airborne sensors.

7. OUTLOOK

ADS40 sensor development is proceeding in four major areas: performance, features, workflow, and data fusion. As a market leader in high-end digital imaging sensors and geospatial imaging software, Leica has been in a unique position to assess market needs for technology and workflow improvements. In particular, the U.S. Department of Agriculture NAIP program has paced utilization of the ADS40 to map millions of square kilometers in a very short time period, and has contributed greatly to the focus of our internal development programs.

Every component of the ADS40 is being continuously examined for performance and feature enhancements. This, of course, includes improvements to the sensor head, data storage, GPS/INS and control electronics subsystems. Many improvements, especially in firmware, benefit users automatically when Leica's Support staff updates internal software. An example of this is the addition within FCMS of automated integration time, allowing optimized exposure and minimized GSD for *each* CCD line. In addition, Leica continually looks for improvements in flight planning, in-flight sensor control and management and sensor mount systems. While revolutionary hardware enhancements are not scheduled in the coming months, Leica continues to push the performance and feature envelope in areas such as radiometric calibration and color management, resulting in ever-higher quality image product with consistently less manual intervention.

The productivity of large scale mapping applications is also being improved through the use of linescan technology. Leica provides enhanced feature extraction ease from quasi-orthogonal line perspective imagery being presented to the operator and from advanced point matching techniques. This type of sensor imagery will offer better performance, as measured by both accuracy and amount of manual intervention, than imagery from frame sensors.

More importantly, Leica is working on several areas of the "pixel carpet workflow" to further increase accuracy and reduce processing time. These efforts present the greatest potential return on investment gains for our customer base, since flight data acquisition represents only a fraction of overall data production cost.

For example, the ADS40 does not suffer the frame to frame registration and patching issues of framing technology sensors. Therefore, developments are now underway to exploit the inherent advantages of pushbroom technology during the processing phase, including the use of multi-image point matching. This will result in data quality superior to framing sensors due to a larger quantity of image points with constant stereo viewing angles. The workflows will also become faster by taking advantage of high-speed and distributed processing. They will become more automated with smarter algorithms for less manual editing and fewer error sources. We expect processing speed gains by a factor of 2 to 4 over the next year.

Finally, Leica is uniquely positioned in sensor and software technologies to utilize fused data from imaging sensors (pan, color, NIR, thermal, multi-spectral, hyper-spectral), LIDAR, SAR and high-definition survey sensors. The goal is to move from two-dimensional maps to three-dimensional, geospatially located point clouds with each point having its various spectral information “attached”. This will facilitate visualization, feature extraction, and zooming capabilities that will become the future of geospatial imaging applications. Sensor fusion will make available geospatial *information* at a reduced “cost per pixel”. It will also fuel increased demand for the data acquisition capabilities of the ADS40 for the vast terrain data sets mapped with increasing frequency.

In summary, the ADS40 has exhibited a history of consistent improvement in hardware capabilities and associated software. The result has been an increase in both system ease of use and number of applications that can be addressed, as well as the speed and accuracy at which data products can be produced.