

## RESULTS FROM TEST FLIGHTS OF THE LH SYSTEMS ADS40 AIRBORNE DIGITAL SENSOR

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**KEY WORDS:** sensors, aerial cameras, digital photogrammetry, multispectral imagery

**ABSTRACT:** After its introduction at the ISPRS Congress in Amsterdam in 2000, the LH Systems ADS40 Airborne Digital Sensor has undergone extensive final tuning, flight tests and calibration, culminating in first deliveries to customers in autumn 2001. Recent tests have included investigations into the geometric and radiometric performance of all seven channels - three panchromatic and four multispectral - using imagery acquired at several flying heights over various types of terrain in Switzerland, Japan and Italy.

### 1. INTRODUCTION

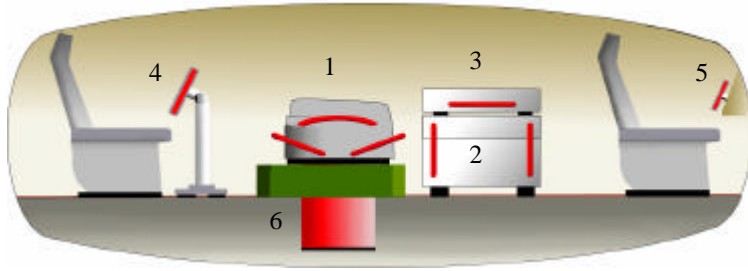
Launched at the XIX<sup>th</sup> ISPRS Congress in Amsterdam in July 2000, the LH Systems ADS40 Airborne Digital Sensor (fig. 1) ushered in a new era of digital photogrammetry, appropriately timed at the outset of a new millennium. Developed jointly with Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Centre – DLR), the ADS40 was the first airborne digital imaging device capable of performance, in terms of resolution and coverage, in a similar range to the established aerial film cameras, with their 23 x 23 cm format and resolutions in excess of 100 lp/mm.

A major advance of the sensor is that the ADS40 provides seamless strip imagery as along each flight line. This was a major innovation: extensive airborne use had been made of digital frame cameras, but these devices' 4K x 4K (or smaller) formats seriously limited coverage, a shortfall that could only be made up through closely spaced flight lines and enormous numbers of images - a formula with little appeal to the traditional photogrammetric organization. In terms of radiometric performance and end-to-end digital workflows, the ADS40 represents significant progress through combining photogrammetric performance with the significant advantages of digital imagery.

The ADS40 represented a second major advance. It was designed not only to meet photogrammetric requirements in terms of coverage, resolution and accuracy, but also to acquire multispectral imagery and thus appeal to sectors of the remote sensing market. This coalescence of photogrammetric precision, designed for positional accuracy of processed data, with capabilities for image analysis and interpretation, for example segmentation or classification, was novel and groundbreaking.

### 2. DESIGN PRINCIPLES

The ADS40 has been well-documented elsewhere (Sandau *et al.*, 2000), and the briefest summary suffices here. The basis of the design is the three-line-scanner principle, attributed – at least in its digital manifestation – to the German O. Hoffman in the 1970s, whereby linear arrays on the focal plane capture imagery looking forwards, downwards and backwards from the aircraft (fig.1). These arrays are panchromatic and in the ADS40 consist of pairs of 12,000-pixel arrays, one member of the pair staggered laterally from the other by half a pixel (3.25 µm). The result is that every portion of the ground surface is imaged thrice, far superior to the 60% triple coverage in typical film aerial photography. Also on the focal plane are four further 12,000-pixel arrays, acquiring imagery, through interference filters, in the red, green, blue and near infrared bands (fig. 2). A device called a trichroid, which is a beam splitter designed for minimum loss of energy, ensures that the incoming RGB light from a strip of terrain is detected by the three RGB-sensitive linear arrays, even though these are physically separate on the focal plane. The performance of the CCD arrays and the filters is maximized through the use of a complex, innovative telecentric lens, whereby light rays impinge upon the focal plane at right angles regardless of their angle of incidence at the front nodal point. The ADS40 is accommodated in the same PAV30 gyro-stabilized mount used for film cameras (fig.1 and 4). An onboard control computer with a mass memory, consisting of a high-capacity ruggedized disk array, records the data at a maximum rate of approximately 100 GB per hour of flight.



- 1 Sensor Head SH40 with:
  - Digital Optics DO64
  - IMU
- 2 Control unit CU40 with:
  - position & altitude computer POS
- 3 Mass Memory MM40
- 4 Operator Interface OI40
- 5 Pilot Guidance Indicator GI40
- 6 Mount PAV30

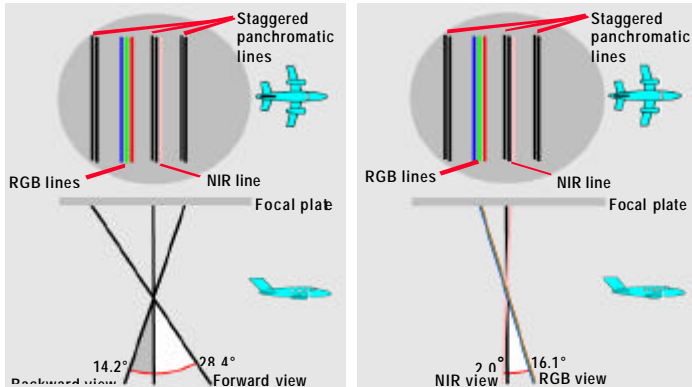


Figure 1. From left to right: ADS40 Airborne Digital Sensor; ADS40 components; focal plane layout.

The post-processing of the imagery as described in Tempelmann *et al.* (Tempelmann *et al.*, 2000), is rather different from the approach used for decades with frame imagery. In the first place, the raw imagery, after correction for hardware-based radiometric factors, lens distortions, etc., can be dramatically different from a frame image owing to the movement of the aircraft, radically altering the parallelism of the scan-lines on the ground. In the case of the ADS40, however, use has been made of the IMU integrated in the Sensor Head SH40. The IMU from the Applanix POS system provides a very accurate vertical reference and drift correction to the gyro-stabilized mount PAV30, thus following the principles described in Collinson, (Collinson,1996), and Hoffmann *et al.*, (Hoffmann *et al.*, 1993). The edges of the “raw” strips are therefore already quite straight and will not receive any large lateral correction.

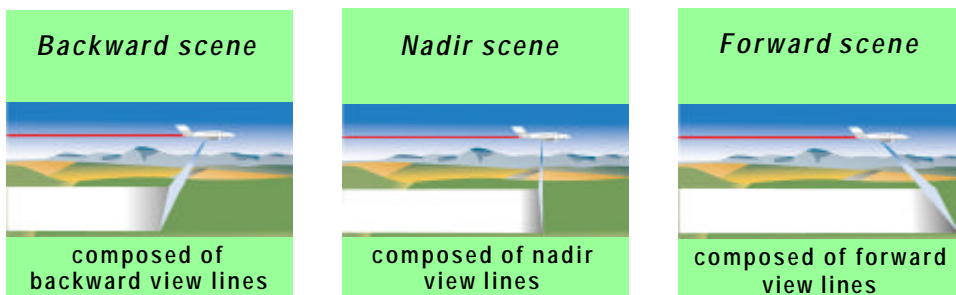


Figure 2. Three-line scanner principle.

### 3. TEST FLIGHTS

The tests covered the assessment of the performance characteristics of:

- the telecentric lens
- the beam splitter trichroid
- the narrow band interference filters that influence the multispectral image quality
- the staggered pairs of CCD lines used for the panchromatic bands
- the airborne GPS
- the inertial measurement unit (IMU) system to determine position and orientation
- data transfer and storage techniques for the on-board mass memory (ruggedized hard disk array).

Investigations of the post-processing software included:

- downloading from the mass memory
- the specially developed sensor model
- triangulation using the three panchromatic bands together with GPS and IMU data gathered during flight
- rectification
- digital terrain models
- orthophotos
- mosaics
- feature extraction

An important aspect will be the assessment of algorithms to generate true color imagery from the spectrally non-overlapping RGB bands. The combined results of the various tests provide initial indications not only of the compliance of the ADS40 with specifications published by LH Systems prior to full production, but also of its success in reaching its goal of achieving photogrammetric accuracy and coverage whilst offering the advantages of remote sensing in terms of the processing of multispectral digital imagery for end user applications.

The first series of test flights, conducted in Switzerland, consisted of imagery of two areas. In each case, a small block was flown several times, consisting of four parallel strips with two strips at right angles, at a flying height approximately 2000 m above ground (for example, fig. 5). At 2000 m, with a principal distance of 62.8 mm and a pixel size of 6.5  $\mu$ m, the ground sample distance was 20 cm, or 10 cm allowing for the staggered arrays in the panchromatic. The blocks were triangulated, as outlined below, using a new variant of LH Systems' bundle adjustment software ORIMA. The results from one of the experiments are summarized in table 3. The standard error of unit weight was less than a pixel and in accordance with normal expectations, based on aerial triangulation theory and error propagation, from precise measurements and modern point matching on high-quality digital imagery. Subsequent test flights in Japan included different types of blocks. A small block for test purposes was flown over a customer's airfield at Chofu, then a large block over Tsukuba consisted of four lines, each more than 20 km long, and two cross strips, for a total flying time of over two hours, resulting in over 200 GB of data, again with a ground sample distance of 20 cm. Further the ADS40 system was accepted by the civil aviation authorities of Japan as being airworthy and fulfilling the required safety standards. Finally a series of test flights in Northern Italy delivered proof of the capability to produce quality RGB and False Color images over urban, rural and coastal areas.

Location	Waldkirch	Sion	Chofu	Tokyo	Tsukuba	Parma	Pavia	Adria	Verona
strips flown	8	8	4	2	4	8	3	3	3
shape	block	block	block	single line	block	single lines	block	block	block
cross-strips	yes (3)	yes (3)	yes (2)	-	yes (2)			no	no
flying height (above ground)	2000 m	1750 m	1950 m	1950 / 2750 m	2000 m	1500 / 1800 / 2000 / 3000 m	1600 / 2300 / 5750 m	1550 m	1500m
general direction	E-W	120°	E-W	E-W	N-S	120°	E-W	160°	120°
GSD [cm]	20 cm	17 cm	20 cm	20 & 15/30 cm	20 cm	15 & 20cm	15/30/50cm	15cm	15cm
Number of CCD's	7	3	7	10	7	7	7	7	7
Total project size	10.1 GB	5.96 GB	73.6 GB		126 GB	85.2 GB	64.5 GB	111 GB	

Table 1: Summary of ADS40 test flights between April and June 2001.

#### 4. SEAMLESS STRIP IMAGERY

One of the major advantages of three-line airborne digital sensor imagery over surface array sensors is that all processes are based on strip imagery (Fig.3). The continuous stereo model, which is as long as the flown strip, is a seamless scene in all stages of photogrammetric processes such as rectification, minification, automatic point matching, block adjustment, DEM generation and orthophoto generation. Handling imagery strip-wise in large blocks reduces administrative overhead in the software significantly, eliminates tedious mosaicing of numerous individual images and makes mosaicing of large blocks easier, safer and less time consuming.



Figure 3: Seamless Nadir B&W strip image of Sion (length 14 km in this example).

## 5. INSTALLING ADS40 SYSTEMS



Figure 4. From left to right: installation in a Cessna 208B Caravan in Japan; installation in a CASA 212 in Italy.

### 5.1. Installation in a Cessna 208B Caravan in Japan

The installation in April 2001 was straightforward owing to the fact that the aircraft is also used for aerial survey with an LH Systems RC30 and thus the same gyro-stabilized mount PAV30 can be used. 2½ hours after the installation crew and the ADS40 arrived at the airport, the aircraft took off for the first flight. A very rewarding side effect was that the Japanese Aircraft Association approved the installation for airworthiness and safety without any objections.

### 5.2. Installation in a CASA 212 in Italy

This installation in June 2001 took only 1½ hours, the major obstacle being the adaptation of the power plugs. This spacious and slow flying aircraft (120 – 150 knots) of course was ideal for installation and flight-testing. On some of the test flights the ADS40 was flown together with the Daedalus MIVIS scanner and it will be interesting to see the comparison of the two sets of digital images. Again the fact that an LH Systems RC30 and PAV30 mount are in use in this aircraft contributed to the effortless installation.

## 6. GROUND PROCESSING

The ground processing approach is summarized in table 2. The mass memory MM40 is removed from the aircraft and connected to a docking station on the ground, typically a high-end PC with a SCSI interface. The images and metadata are downloaded, which can take several hours since the capacity of the mass memory is around 0.5 TB. After data download, rectification based on position and attitude data from the integrated GPS/IMU unit provides stereo viewable images and both manual measurement of ground control points and automatic measurement of tie points can proceed in the normal way. Block adjustment eliminates remaining parallax in the rectified images. The resulting images are precise and parallax-free and can be viewed stereoscopically, then used, for example, for collecting and editing map features. Similarly, further photogrammetric production processes, such as DTM generation, orthomosaics or visualization can proceed on the basis of these images.

<b>Level 0 - Raw data</b> (geometric raw images -TIFF and other formats, processed orientation data)	<b>Level 1 - Rectified data</b> (fully corrected, stereo-viewable, panchromatic images and fully corrected, multispectral images)	<b>Level 2 - Geo-coded data</b> (panchromatic and multispectral orthophotos)
<b>LH Systems ADS Level 0 Generator</b> and Applanix POS Proc	<b>LH Systems ADS Level 1 Generator, SOCET SET, DPW, ORIMA</b> or third party photogrammetric workstations with ADS sensor model	

Table 2: Levels of ground processing of ADS40 data.

Ground processing of test data in the period described in this paper was limited to Level 0 and Level 1 processing. Duration of Ground Processing varied strongly depending on the following for Level 0: available computer, processing power, amount of data recorded, compression level, quality of recorded GPS data (amount of visible satellites), rectification strategy. And for Level 1, the critical factor was automatic point matching strategy.

Ground Processing can require from several hours to entire days. Two thirds of processing time is batch oriented, so it is mainly a question of priority allocated to timely completeness and consequently how much computer power is deployed to master these tasks. Automatic point matching can take several hours per hour of recorded data. On the other hand, bundle adjustment with ORIMA lasts only a few minutes for each hour of recorded image data.

## 7. AERIAL TRIANGULATION

Level 1 rectified images based on GPS/IMU data produce good stereoscopic views, which are more than good enough for many applications. However, the use of these rectified images for feature extraction in a stereo photogrammetric workstation at large viewing scales is another issue. As thoroughly described by Greening *et al.* (2001) aerial triangulation is not obsolete; the authors contended that the use of IMU in combination with GPS is still considered to be in its infancy. Our experience is that, after rectification, stereo images still have small amounts of parallax, which can disturb and tire the stereo operator. Although we support all efforts aimed at reducing or even eliminating ground control, we still maintain that, for parallax-free imagery, point matching and bundle adjustment are required, not to mention the peace of mind achieved by being able to crosscheck that geo-coding has been performed correctly.

### 7.1. Aerial triangulation based on GPS/IMU rectified imagery

The ADS40 is the first commercial airborne digital sensor offering such highly integrated GPS and IMU sensors. GPS offers the dual benefit of providing straight and predetermined flight lines as well as supporting the IMU with accurate positions. The IMU provides attitude data in-flight to keep the gyro mount almost perfectly vertical and aligned. The use of GPS and IMU requires that certain measures be taken before and after the flight. GPS on-the-fly techniques are already well known. The use of an IMU requires two actions:

- in-flight alignment, which consists of three minutes of straight flight followed by two 360° turns before and after image data is recorded for each survey area.
- occasional correction or check of the IMU misalignment by flying one and the same flight line in both directions.



Figure 5: From left to right: Sion block flight path, in-flight IMU alignment loops and double line flown in opposed directions to correct for IMU misalignment. The results of such a flight are perfectly parallel flight lines, as seen in the superimposed rectified strip imagery of the Sion block.

### 7.2. Ground control for the Sion aerial triangulation block

One of the first aerial triangulation tests was conducted over the area of Sion in the southwest of Switzerland. No preparations were made to signalize points or determine ground control points in advance. On the day of the flight the GPS ground reference station was switched on. GPS measurements of the ground reference station and of the ground control were emailed to us by the local surveyor the day after the flight. The results are shown in table 3.

Strips	4
Cross strips	2
Control points	18
Orientation fixes	216
Tie points	5420
Bundle adjustment options	Self-calibration; automatic blunder elimination
$\sigma_0$ (standard error of unit weight)	5.3 $\mu\text{m}$ (0.8 pixel)
RMS for ground control points	<5 cm

Table 3. Summary of the ORIMA results for Sion block.

### 7.3. Color and false color composites from ADS40 imagery

Very attractive color composites were made by selecting a coastal region from the Adria image strip and processing them in SO CET SET<sup>®</sup>. The JPEG files were transferred to Photoshop, where the final area selection was made.

## 8. CONCLUSIONS

This recent progress is a sound reflection of the ADS40 development. The ADS40 was designed as a high performance tool for both photogrammetry and remote sensing, built around cutting-edge and innovative technologies. However, the success of the device in terms of results transmitted to the end user of the imagery is contingent on a robust workflow consisting of software components sourced from several places, both in-house and third parties, which have to be linked together to achieve effective, smooth processing of the massive data volumes that the ADS40 will routinely generate. An essential component is that a reliable, long-term archiving system is necessary to handle storage and dissemination of the data, as provided by LH Systems with its new GDM100 GeoVault Data Manager. There is no longer a film “in the can” as a back-up of last resort.

Despite the above positive report, it must be understood that extensive work is continuing to optimize the performance of the multispectral bands and establish the most useful workflows on the remote sensing side. This process is not yet complete, but encouraging progress has been made so far and will be reported in due course.

At the time of writing (August 2001), the ADS40 has completed an extensive program of test flights, firstly under factory control in Switzerland, and secondly jointly with customers in Japan and Italy. The latter series of tests involved successful compliance with Japanese Aviation Association standards for air safety. Final system tuning is now taking place and at the same time ADS40 production models are progressing along the assembly line. Product acceptance is guaranteed and current indications are that a steady flow of orders will continue as the product diffuses from the early adopters – typically larger aerial survey service companies that operate several film cameras and a fleet of aircraft – to a broader sample of aerial survey and photogrammetric firms, together with other prospects not in the traditional photogrammetric world.

## 9. REFERENCES

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