Raising the Bar for Multi-Band, High-Resolution Airborne Imagery

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ABSTRACT

Since the ADS40 introduction to the market in 2001, more than 50 are in use worldwide producing digital large format imagery and image strips in great quantities. The technology of the 3 line scanner was a pioneering step and generated a lot of interest within the geospatial community. The overwelming acceptance of this new technology has proven that large format sensors generate a good return on investment and that "airborne digital" is here to stay. Only 6 years after the introduction of the first generation of the ADS40, the ADS40 2nd generation was introduced and is characterised by two new sensor heads. The new ADS40 sensor heads SH51 and SH52 are designed around a unique beamsplitter device, which closely co-registers four spectral bands - all in the same, equal native GSD resolution. Together with an increased signal to noise ratio, new applications are happening and the bar is raised for multi-band, high-resolution airborne imagery for remote sensing and photogrammetry. The SH52's in-track, four-band stereo imaging capability redefines large format sensor performance standards. This paper highlights these new developments and the new capabilities they offer.

1. INTRODUCTION

The first generation ADS40 already offered a choice of 4 different focal plates. Other improvements such as four-band co-registration without pan-sharpening, RGB and CIR stereo capability, 5cm native resolution 5-band imagery and simpler calibration methods were demanded. To address these, the ADS40 2nd generation was developed with two new focal plates represented by the two new sensor heads SH51 and SH52. Apart from the new Tetrachroid 4-band beamsplitter, other benefits of the new design are a higher geometric stability, reduced irregular distortions and a new camera model for self-calibration by bundle adjustment.

While the ADS40/SH51 is tailored to efficient orthophoto production, the ADS40/SH52 is the universal solution. It provides the additional CIR stereo capability requested by end users for such remote sensing applications as forestry inventories, agriculture and urban vegetation inventories without having to resort to pan-sharpened imagery.

The launch of the ADS40 2nd generation in December 2006 generated a large demand for an upgrade of first generation ADS40's. This technical possibility was considered in the earlier design Leica made and to date nearly one third of all SH40 users have opted to upgrade to an SH51 or SH52.

2. DESIGN OF THE NEW ADS40 2ND GENERATION SENSOR HEADS

In the years since the ADS40 introduction, micro-structured dichroic filters have become more manageable and new alloys with uncommon but useful thermal properties became available. [1] The real technological driver for a new sensor head design was the micro-structured filter, allowing a far better use of the three CCD line-pairs a single chip already being used in the SH40. Individual filters for each CCD line allowed four closely co-registered spectral bands on two line pairs: blue/near infrared (NIR) and red/green. The remaining pair can be used as a staggered panchromatic pair. Using a new alloy for the focal plate structure freed up space for larger IMU (Inertial Measurement Unit) systems. The electronics re-design improved the signal quality and provided advanced functionality and reliability. It also allowed a much more compact design

An interesting side effect of the new optical design of the filters is a greatly reduced amount of local image distortions. This allows a much simpler camera model for the bundle adjustment and a straightforward approach to self-calibration of the sensor head. The ADS40 2nd Generation is therefore the first Large Format digital Camera whose calibration is based exclusively on an in-situ geometric self-calibration eliminating the need for laboratory calibrations.

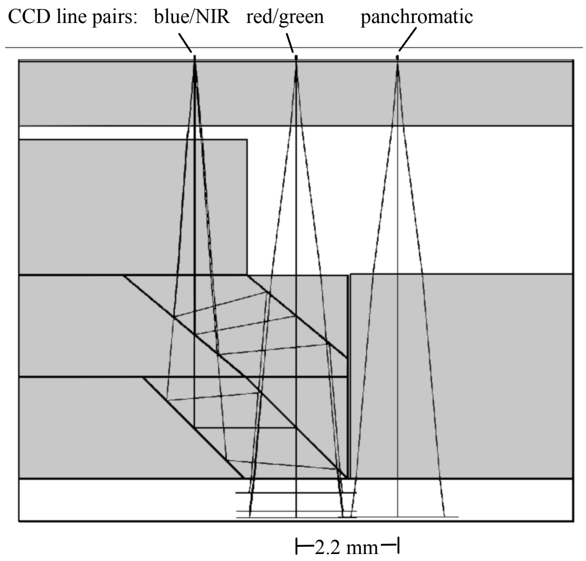

Fig. 1: The Tetrachroid, optical glass, shown in grey

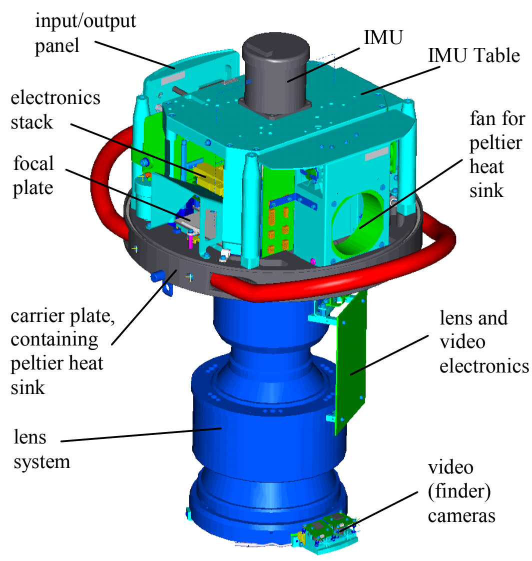

Fig. 2: 3D Model of a SH51/52

The mechanical design of the SH40 regarding the relative stability of the lens system, focal plate and the IMU remained proven and unchanged. However, it was limited to small sized IMU systems. In the SH51/52, the IMU sits on a highly thermally conductive aluminium-silicon alloy table. The table is above the focal plate and the electronics, exactly on the optical axis and directly connected to the focal plate and lens interconnection ring (fig.2). The alloy table is designed to eliminate thermal rotations and to withstand all practically possible shocks without significant deflection. It can carry large sized IMU's, up to the size and weight of the highly precise Honeywell µIRS and allows IMU exchange by the user.

3. TWO NEW FOCAL PLANES FOR ALL MULTI-BAND APPLICATIONS

The two main goals of the SH51/52 development were to make the system a far better remote sensing tool and to enable it to work at shorter integration times. The step toward a better remote sensing tool became possible by a micro-optical filter device in front of the CCD lines in combination with a new beamsplitter design. The advantage of this patented "Tetrachroid" design over the SH40 "Trichroid" is that it also co-registers the NIR CCD line to the RGB lines.

The design of the Tetrachroid looks fairly simple (fig.1), but it required that five different dichroic filters (panchromatic, red, green, blue, NIR) had to be combined onto a single glass plate, each colour filter being 16µm wide, 80mm long and perfectly straight. Creating 3.5µm thick filter packets, consisting of up to 40 layers, with an edge width of only 4µm, is fairly close to the limits of lithographic and coating processes. Also, aligning the filter glass to the CCD line with micron tolerance and mounting it within a distance of at least 30µm (to avoid near field effects) and not more than 60µm (to avoid vignetting) to the CCD surface was a real, yet successful, challenge.

Although the Tetrachroid development was difficult and long, it was worth the effort. It offers 4 co-registered image bands with the same rectangular spectral shape as the SH40 Trichroid - but now simultaneously for true colour, false colour or four-band images (fig.3) and fig.4). Each image has the full 12,000 pixel resolution across the swath (fig. 5).

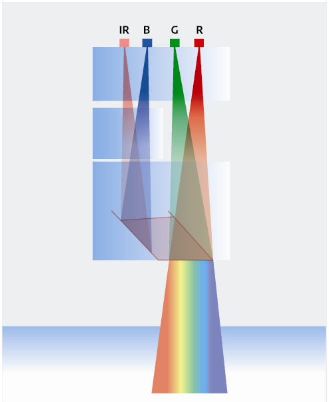

Fig. 3: The Tetrachroid four-band beamsplitter

The Tetrachroid combined with the 3-line-pair CCD opened new possibilities for the focal plate design. The three-line principle is maintained through the three panchromatic channels in forward, nadir and backward viewing angles. The inclusion of one or two Tetrachroids in the focal plate makes it possible to satisfy the demand for an efficient orthophoto production sensor (SH51) with one or supply a truly universal sensor (SH52) covering all applications and especially, remote sensing as well as efficient orthophoto production with two.

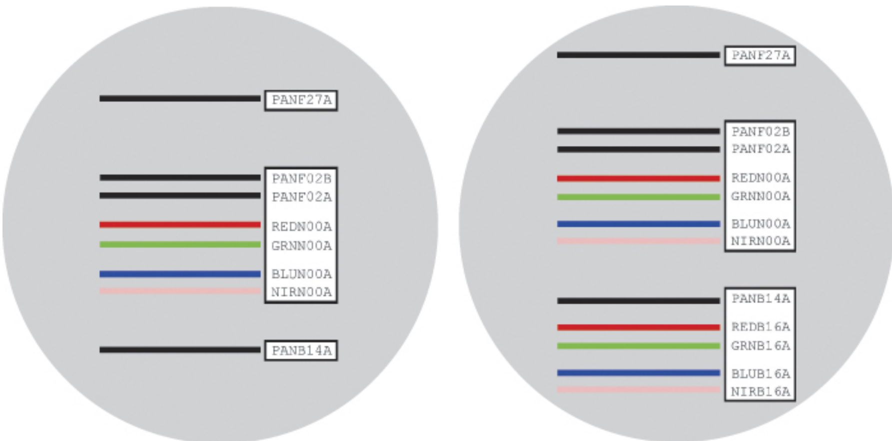

Fig. 4: Focal Plate of SH51 - and - Focal Plate of SH52

These two focal plate arrangements with 8 and 12 CCD lines respectively adhere strictly to the 3-line principle which allows the generation of geometrically rigid and accurate images or image strips through rectification and bundle adjustment.

The 100% forward overlapping strip images (fig.5) provide a very good base to height ratio inherent in line sensors. The height accuracy is therefore superior to digital frame cameras with rectangular patched frames that have a limited dimension in flight direction.

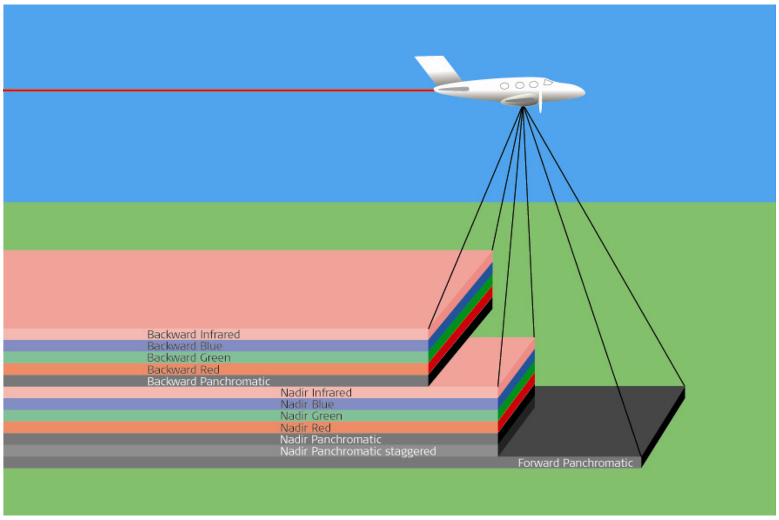

Fig. 5: Collection of strip images with two Tetrachroids in the SH52

The fast development of digital electronics, especially the FPGA's (Field Programmable Gate Arrays), allowed the replacement of the original electronics rack by a small stack (fig. 2) of only four boards while providing even greater functionality.

The use of FPGA's also led to the most important advantage from the user's point of view, of a largely reduced noise level. SH51/52 images contain little more than the white noise of the CCD line. Together with the higher transmission of the Tetrachroid, the sensitivity (i.e. SNR) of the SH51/52 colour lines is about four times better than that of the SH40. An analysis of images flown under different light conditions indicates that the same visual quality of orthophotos can be obtained at one-fourth of the SH40 integration time of the SH40. The SH51/52 allows the capture of sharp, radiant good colour images of perfect registration at integration times down to 1.25ms, even under winter light conditions. This allows a GSD of 5cm, of all channels (panchromatic, RGB, NIR) at standard flight speeds, even in low light conditions (fig.6).

Fig. 6: Date/Time: 1 Nov. 2006 / 3:20 p.m. Latitude: 47° North, Ground Speed GS: 140 knots, GSD: 5cm, Sun-Angle: 13°, Weather: overcast -> Equivalent sun-angle: 8°

The ADS40 with the sensor heads SH51/52 and SH40 is still the only large format digital imaging camera capable of providing equal native GSD resolution in panchromatic, true colour and colour infrared images. With the exception of mid-format digital cameras, other patching large format digital cameras still have to resort to additional resampling and pan-sharpening steps. These steps reduce image quality and make its use for remote sensing applications questionable. fig.6 shows a complete set of geo-referenced and perfectly co-registered panchromatic, colour-infrared and true colour images taken on the same flight under winter lighting conditions and all at the same 10cm resolution 5cm.

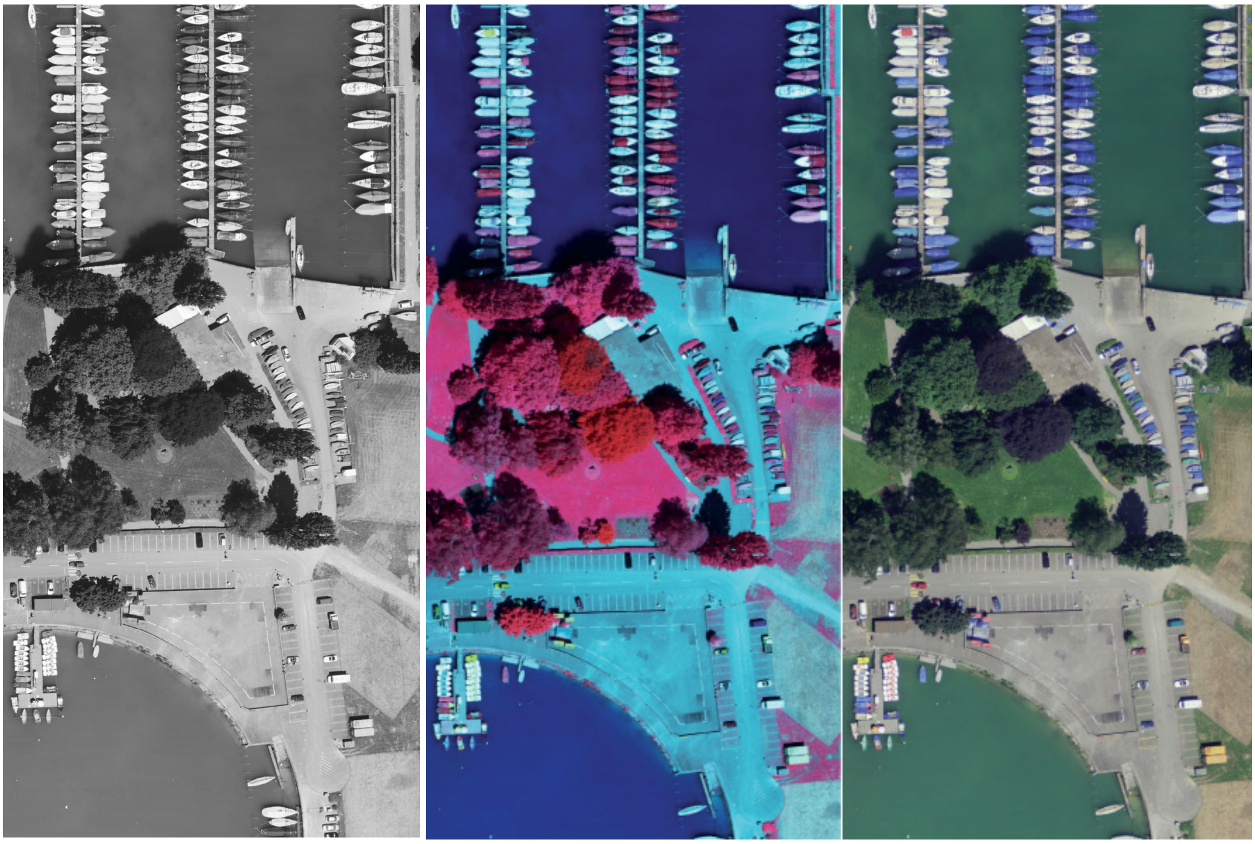

Fig. 7: ADS40/SH52 co-registered Pan, RGB and CIR images. Romanshorn, GSD=10cm, Flying height=1000m

4. ABSOLUTE RADIOMETRIC CALIBRATION

It is quite astonishing that the imaging community is critical about geometric calibration, but very lenient when it comes to radiometric calibration. Digital cameras have spectral and radiometric properties superior to analogue film cameras. Due to its radiometrically stable construction, the ADS40 sensor is capable of capturing images for cartography as well as for remote sensing applications. With the increased demand for larger projects, for sensor data fusion, as well as for change detection purposes, it is necessary to produce comparable images under different flight conditions (weather, camera system, etc.). This is not possible with classical film cameras since comparable image quality requires absolute radiometric calibration of the imaging system, before atmospheric correction, reflectance calibration and BRDF correction can take place. [6].
The methods for satellite laboratory radiometric calibration however, can also be used for digital airborne cameras. A laboratory radiometric calibration of the ADS40 is made with a calibrated integrating sphere to determine dark signal, lens falloff, and radiometric gain for each sensor line. For the ADS40, a linear radiometric model is sufficiently accurate. The knowledge of the system's spectral response allows a more accurate calculation of the radiometric calibration coefficients and is a check for system integrity. To provide a regional digital camera service, Leica Geosystems are

establishing radiometric calibration facilities are being established at several Leica worldwide service sites to implement this straight forward calibration approach.
These calibration facilities ensure that radiometric calibration in all regions provides cameras of equal calibration to the photogrammetric and remote sensing community. For more details see [2] Beisl, U. Absolute Spectroradiometric Calibration of the ADS40 Sensor. ISPRS Comm I, WG I/I, Paris 2006.
The ADS40 is designed with four non-overlapping spectral channels in the blue, green, red, and NIR region together with panchromatic stereo channels.

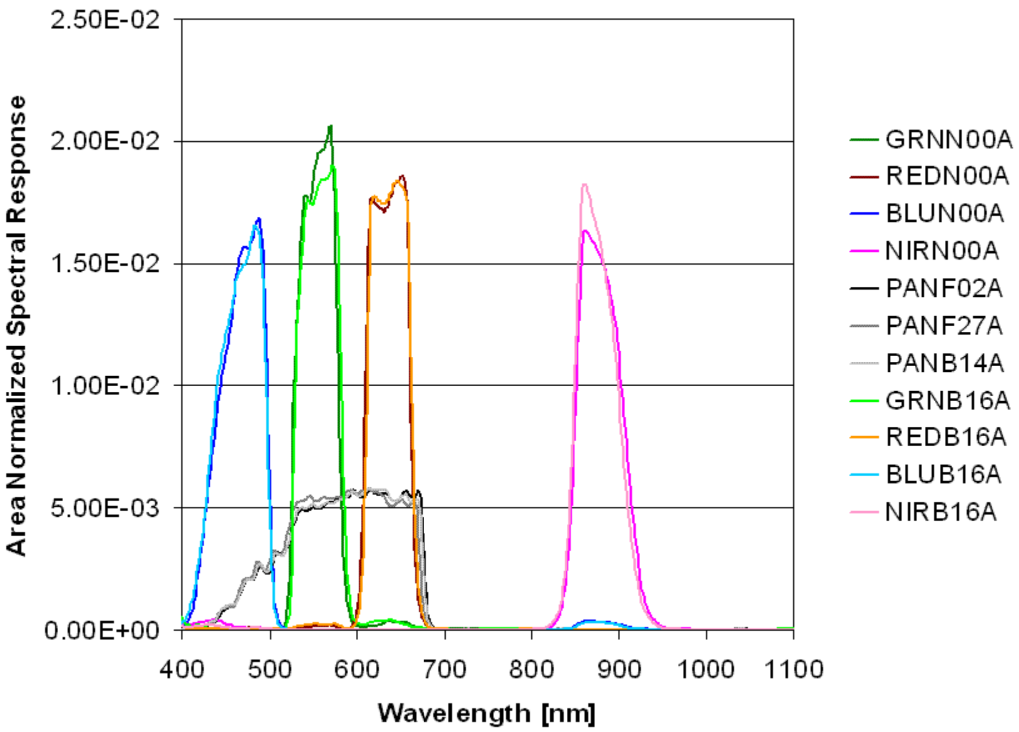

Fig. 8: Spectral response of SH52 bands normalized to unit area as seen through a backward and nadir viewing Tetrachroid

From the ADS40 Ground Processing software GPro v3.0 onwards, the radiometric calibration factors are used to calculate standardized images for photogrammetry. For remote sensing applications, radiance calibrated images can easily be calculated, which are the basis for further data products like ground reflectance images [3] (Beisl and Woodhouse, 2004, [2] Beisl, 2006 and other classification applications[6] Bühler et al., 2007.

5. COMPLETE SUITE OF SENSOR RELATED SOFTWARE FOR ALL SENSORS

With the introduction of Leica’s IPAS10 (Inertial Position & Attitude System) and the Leica FPES (Flight Planning & Evaluation Software) in 2006, the strategy of offering the user a complete workflow of sensor related software was achieved. The main benefit is a seamless data flow from flight planning to all photogrammetric applications for all Leica sensors. Training and support cost is thereby reduced when operating different types of Leica sensors.

The main benefits of FPES are that flight planning, proposals, flight reporting and invoicing can be made from the same tool. FPES blends with the FCMS (Flight & Sensor Control and Management System) and can be used on all types of geographic and grid coordinate systems. They allow efficient flight planning based on a DTM for all types of sensors including RC30, ADS40, ALS50 and other frame and line sensors as well as sensors operating in an ON/OFF mode.
The 4 models of the Leica IPAS10 replace the Applanix POS systems previously offered with the ADS40 and the ALS50 and provide additional functionality not available to the users of POS IMU systems, like the PPP technology. The introduction of PPP algorithms/technology into the post-processing of GPS signal observations solves carrier-phase ambiguities without the need for a base station. This eliminates a logistics restriction associated with GPS use with any airborne sensor (ADS40, ALS50) and eliminates the requirement of a DGPS receiver on a known point within 50km of the operating sensor and allows benefits to the user of greater aircraft disposition flexibility when capturing imagery of very large and remote areas (forest, desert, plains etc.) and saves project preparation and operating costs. The software module using PPP technology is called IPAS PPP.

		NUS4	DUS5	NUS5	CUS6
Absolute accuracy after post-processing (RMS)	Position	0.05 - 0.3 m	0.05 - 0.3 m	0.05 - 0.3 m	0.05 - 0.3 m
	Velocity	0.005 m/s	0.005 m/s	0.005 m/s	0.005 m/s
	Roll & Pitch	0.008 deg	0.005 deg	0.005 deg	0.0025 deg[1]
	Heading	0.015 deg	0.008 deg	0.008 deg	0.005 deg[1]
Relative accuracy	Angular random noise	≤0.05 deg/sqrt(hour)	≤0.01 deg/sqrt(hour)	≤0.01 deg/sqrt(hour)	<0.01 deg/sqrt(hour)
	Drift	≤0.5 deg/hour	≤0.1 deg/hour	≤0.1 deg/hour	<0.01 deg/hour

Fig. 9: Specifications of IPAS10 models

FCMS is now the only Flight & Sensor Control and Management System for all Leica Sensors. The flight plan established with FPES can be introduced directly into the FCMS of the sensor and the survey flight will be executed directly from the Operator Interface OI40 or the OC50 [fig.10].

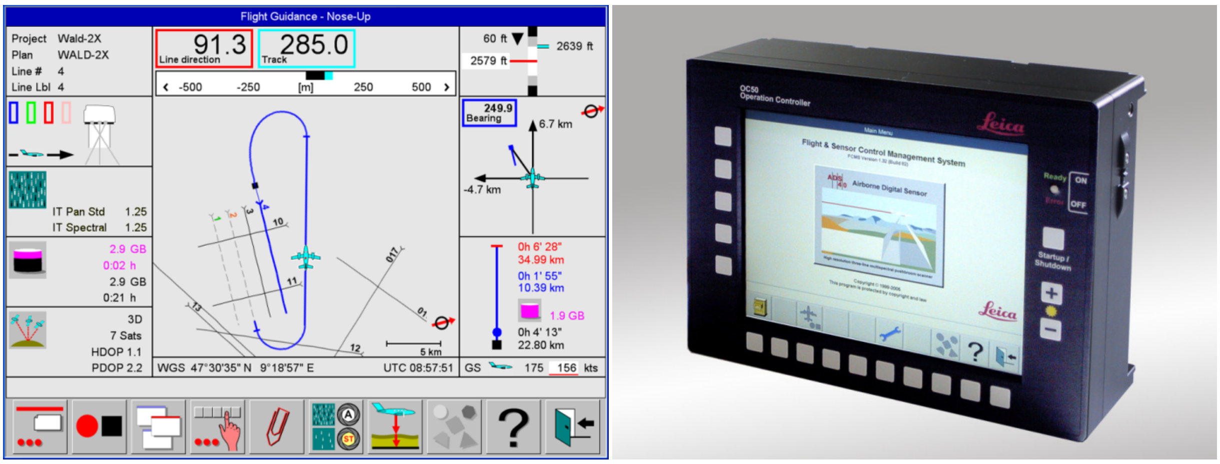

Fig. 10: New FCMS (Flight & Sensor Control Management System) incl. Flight Guidance and the Pilot and Operator Controller OC50 for FCMS

The fourth link in the chain of sensor related software modules is GPro (ADS40 Ground Processing software). This program has evolved from download software to a software tool that provides the complete link from the Mass Memory used in the aircraft to the image deliverables for photogrammetric and remote sensing applications.

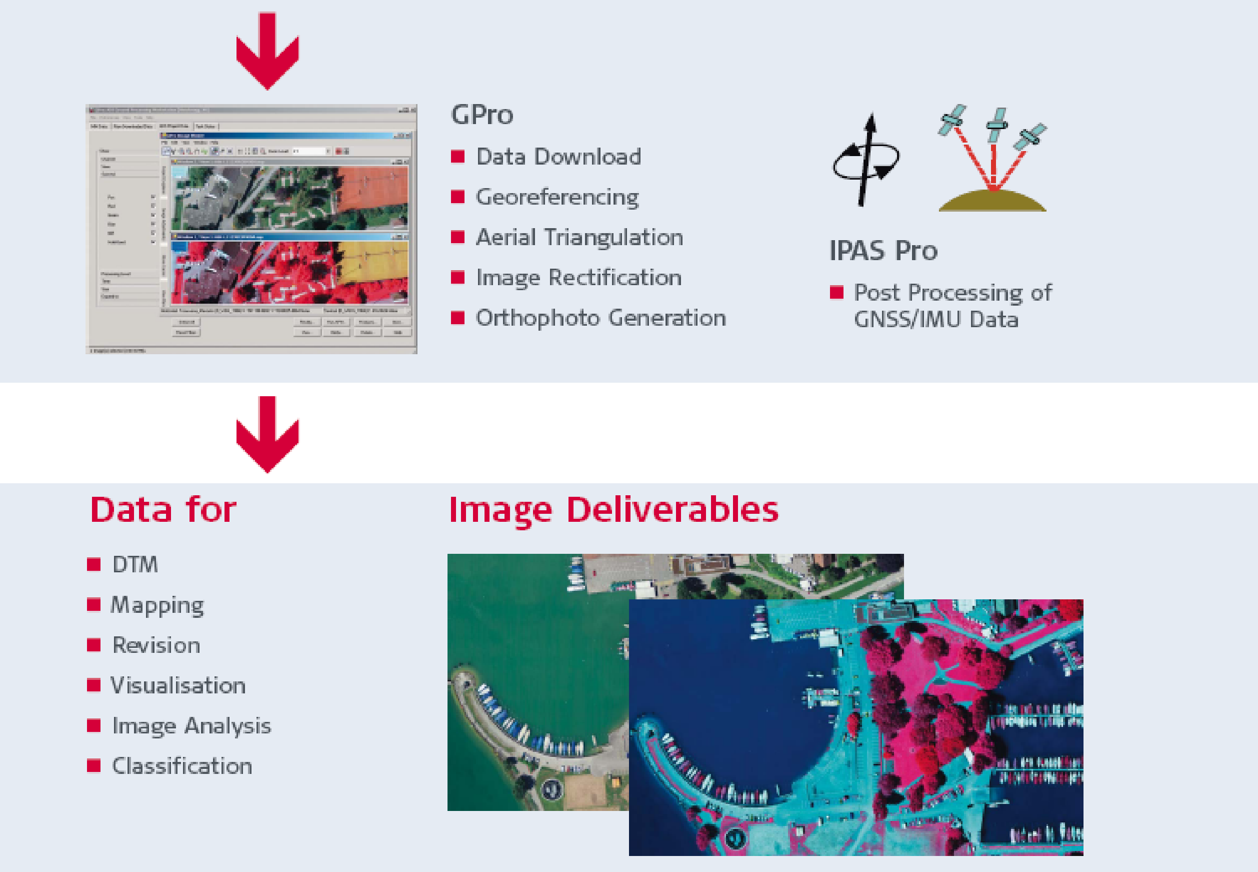

Fig. 12: ADS40 Ground Processing

6. SUMMARY & OUTLOOK

With the introduction of the ADS40 2nd Generation sensors, a milestone has been achieved which was only a vision 10 years ago when the ADS40 development started as a joint venture with DLR. All requirements of multi-band photogrammetry and remote sensing have been achieved. The airborne sensor that provides equal resolution, geo-referenced, co-registered 5-band stereo-imagery has been realized. In the six years since its market introduction, the ADS40 has been sold over 50 times and more than 15 upgrades to the new ADS40 2nd Generation sensor heads SH51 and SH52 are under way.

The future looks very bright for the geospatial imaging community, for which photogrammetry is an important part. In only 6 years, the number of large format airborne digital sensors and cameras has reached a total of over 150 units. Photogrammetry in its algorithmic form will always be present in many types of software programs, sometimes hidden in image processing packages and as standalone Digital Photogrammetric Workstations.

Digital sensors, cameras and laser scanners have now begun implementation of fully digital workflows. Since processing and storage capacities continue to follow Moore’s law (Moore's Law is the empirical observation made in 1965 that the number of transistors on an integrated circuit for minimum component cost doubles every 24 months), a complete digital imaging workflow can be expected. The digital workflow will include photogrammetric processes (algorithms) for real-time or near real-time production of digital products and geospatial data such as Orthophotos, 3D Visualizations, Automatic Thematic Terrain and Object Classification, etc.

Already the combination of digital sensors and cameras with LIDAR are changing the way in which final products are produced in a much shorter time than ever before. It is highly probable that the digital sensors of the future will combine spectral images, thermal images, LIDAR intensity images, SAR images, DTM's, DSM's, etc. All of these sensors work on the basis of geometric relationships. Therefore, it is also most probable that photogrammetry and its algorithms will continue to be the premier tool to produce the perspective imagery that human beings require to make intelligent decisions.
Leica is uniquely positioned in sensor and software technologies to utilize fused data from imaging sensors (pan, colour, 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 clouds of points with each cloud 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 and further the spread, use and awareness of digital imagery and processes. This sensor fusion and innovative computation processes of combining height data from LiDAR and planimetric accuracy from the digital camera integrated through image matching (see [5] Xuan et al, 2007) will demand more on ADS40 data acquisition type capabilities for the mapping of vast terrain areas to be mapped on a regular basis.

7. REFERENCES

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