NEW DEVELOPMENTS ON PUSHBROOM SENSORS

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Commission I, Working Group I/4

KEY WORDS: Digital, multispectral, GPS/INS, Hardware, Pushbroom, Sensor, High resolution, Three-Line

ABSTRACT:

Since its market introduction at the XIXth ISPRS congress in Amsterdam in 2000, the Leica ADS40 has been rapidly accepted by a market that recognizes the value of low unit production costs for area image coverage and performance, geometric accuracy, ease of use, system stability and absolute radiometric calibration. Leica Geosystems's continuous improvement and upgrade philosophy is reflected in the original Leica ADS40 design parameters and additional user requirements, improved materials, manufacturing techniques and computing power as well as conceptual reviews have identified several areas for potential improvement. The 2nd generation Sensor Heads SH51 and SH52 are already in the market. A thorough overhaul of the main sensor concept and components is followed by further improvements in areas such as subsystem integration, data channel management, software developments, standardized interfaces and in-flight data processing.

1. INTRODUCTION

1.1 Three-Line Pushbroom Sensor Leica ADS40

Successful development has over the years been fundamental to the growing success of the Leica ADS40 with its Customers and ensures that the user community continues to benefit from the most recent technological innovations. General technological advances in construction materials and alloys, manufacturing techniques, micro-structured filters and coatings, electronic design technology and computing power as well as conceptual reviews have found implementation in Leica ADS40 2nd Generation Sensor Heads SH51 and SH52 (see [1] Tempelmann, Hinsken 2007).

The Leica ADS40 digital sensor consists of several components (e.g. sensor head, control unit, mass memory storage unit) and subsystems (e.g. stabilized mount, GNSS/IMU positioning system, flight management system), most of which are developed and manufactured in-house ensuring full and effective integration.

1.2 Fields of improvements and new developments

Although the current Leica ADS40 sensor design offers a data channel with a high data throughput, data channels in the future will have to handle data rates of 100 Mbytes/sec or more to meet expected user requirements of more data from multi-spectral imagery, smaller GSD and data from different airborne sensors.

Another potential field of improvement is the in-flight evaluation capability. This has been implemented with the release of V2.2 of Leica's Flight and Sensor Control Management System (FCMS) software, which supports recording and reporting of the actual flight parameters and imagery inclusive of the Leica IPAS20 data. Several ideas are currently being tested to go one step further and to extract relevant data to facilitate in-flight processing. A fully processed orthophoto at the time of landing is a goal desired by many users in the photogrammetric community. The transfer of faster processing power to on-board aircraft computers to enable the production of orthophotos has been a whish since the Leica ADS40 was introduced in 2000 and is critical for time-sensitive applications such as disaster mapping. Highly improved computer power, distributed processing technology and reliable, rugged, hardware components makes this goal realistic in the near future.

2. SENSOR HEAD

2.1 Sensor Heads SH51 and SH52

The newly designed sensor heads SH51 and SH52 represent the latest developments in optics, mechanics and electronics. A revolutionary beamsplitter with dichroitic filters coated on a single plane-parallel glass plate was developed. This Tetrachroid provides fringe-free, high resolution imagery in five bands: panchromatic, red, green, blue and NIR.

Two sensor head configurations are available. SH51 offers eight parallel sensor lines, 4 panchromatic lines (forward, 2 x nadir, backward), four nadir multi-spectral lines (red, green, blue and NIR) based on one Tetrachroid, and delivers imagery for efficient orthophoto production. SH52, provides 12 parallel sensor lines, 4 panchromatic lines (forward, 2 x nadir, backward), nadir and backward multi-spectral lines (red, green, blue and NIR) based on two Tetrachroids, and produces imagery for universal applications and especially for remote sensing applications. SH52 delivers stereo colour and stereo

false colour as well as panchromatic stereo imagery (See [3] Fricker, 2007).

The concept of a temperature stabilized telecentric single lens was maintained in the new system. Mechanical improvements to the basic design of the Leica ADS40 allowed a more compact and rigid integration of the IMU platform above the optical axis and gives the user a choice of IMU units. These improvements have extended the range of Leica ADS40 applications into remote sensing and high resolution photogrammetry. An important side effect of the new senor head improvements is that they have produced a much simpler mathematical sensor model with reduced amounts of local distortion. With imagery taken at different flying heights and an easily flown pattern, this allows system calibration by the user through bundle adjustment together with a logical approach to self-calibration of the sensor head (see [2] Saks, Tempelmann, 2008). The reviewed electronic concept includes FPGA technology.

Both, SH51 and SH52, allow users to collect perfectly co-registered, equally high resolution, fringe-free stereo viewable images in colour, false colour and panchromatic down to 5cm GSD. This is making the Leica ADS40 the ideal measuring tool for applications ranging from remote sensing to large scale engineering applications.
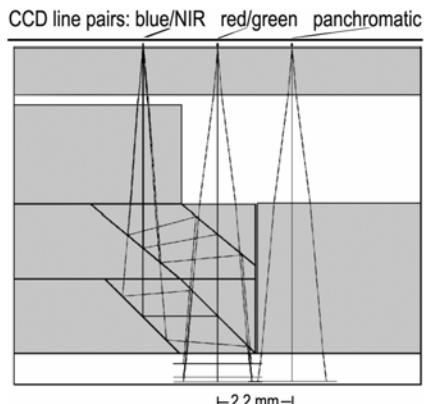

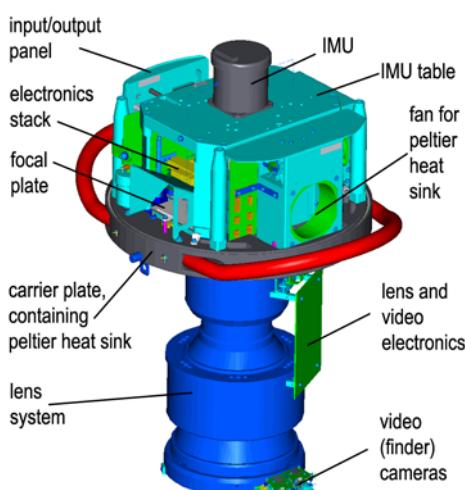Figure 1. The Tetrachroid, glass shown in grey

Figure 2. 3D model of SH51/52

3. DIGITAL COMPUTER AND MASS MEMORY

3.1 Improved Control Unit and data flow concept

The concept includes both airborne data acquisition and office workstation download. The new concept, as graphically illustrated in figures 3 and 4 below, includes both airborne data acquisition and office download.
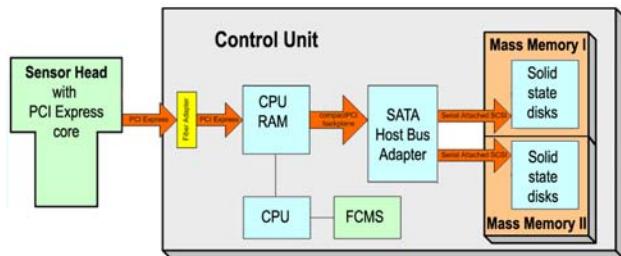

Figure 3. Airborne data flow and recording for ADS

The ADS system consists of the hardware components: Control Unit, Mass Memory, Sensor Head SH51/52, Operator Interface OI40, GNSS antenna, Pilot Interface OC50 and an optional Guidance Indicator (GI50).

In the aircraft, all data i.e. image data from the sensor heads SH51/52, attitude data from the Leica IPAS20 and flight and sensor management data from Leica FCMS, will be stored in the CPU RAM via a PCIe (PCIexpress) interface and standard bus system. Leica FCMS will take control of the image data and transfer via Host Bus Adapter (HBA) to the solid state flash discs of the Mass Memory (MM). The CPU RAM is used as data buffer storage in case the writing of data to the MM is delayed. PCIe allows intelligent error handling and improves the reliability of the data acquisition process. Furthermore, the reduced number of interfaces eliminates a potential error source.

External interfacing has been simplified. One power switch will control both the CU and the SH51/52 and power to the MM will be controlled by Leica FCMS software. The CU Power Controller (CPC) board will be based on a similar component design in the SH52 and will manage all power supply to the system. Temperatures will be measured by the CPC board, which will also control heating and cooling devices and provide temperature protection to the system.

Following airborne data acquisition, the Mass Memory will be connected to a workstation in the office. The image data will be downloaded from the Mass Memory to the workstation. The office station consists of the components: Mass Memory, power supply for Mass Memory, workstation with SATA host bus adapter and cables from host bus adapter to the Mass Memories.
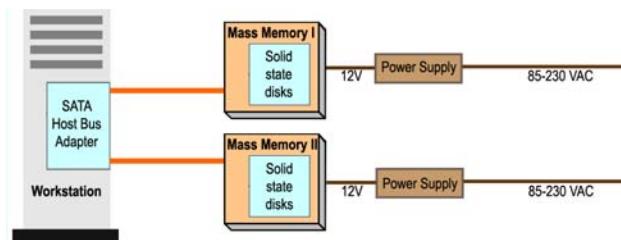

Figure 4. Office workstation download concept

3.2 Data throughput

Users requests for smaller Ground Sample Distance (GSD), down to 5cm, have recently become more frequent. Integration of FPGAs, greatly reduced image noise levels and higher energy transmission due to the Tetrachroid are contributing factors in achieving GSDs of 5cm across all bands and a fourth of previous integration times.

The required data throughput of the data channel is dependant on the number of CCD lines, the number of pixels per CCD line, the pixel clock frequency and the compression factor. The cPCI System and the CPU Blade have to be selected to allow for high bandwidth on the PCI Bus. Special care has to be taken of the data path from the PCIexpress connection to the CPU main memory and from the CPU main memory to the SAS host bus adapter.

FPGA technology is already implemented in the SH51/52 sensor heads. The FPGA of the Focal Plate Module (FPM) digital board can be expanded to perform 10-bit or 12-bit data compression including a lossless (and near lossless) algorithm.

3.3 Data storage

Optimization of the analog signal electronics has led to a four-times increased S/N ratio and a significantly increased light sensitivity in the SH51/SH52 allowing for smaller GSD being captured. This requires data storage at a higher bandwidth, which can be achieved using multiple solid state discs with optimized sustained bandwidth. For practical, large area projects a capacity of about 500GB is desirable. This can be split into two disc packs, which are connected to the host bus adaptor. Mass memories of various sizes will be available to provide the optimal storage capacity for a project. The new Mass Memory will be designed as an exchangeable unit, accessible from the operator side of the Control Unit. It can be connected by sliding it into a floating mounted plug for easy in-flight exchange.

A RAID can be created with the Mass Memories and a standard file system is used to read and write files to the RAID. The RAID will handle the data storage load distribution and can be configured to optimize storage performance of data redundancy. The raw data file structure of image data and meta data blocks will stay the same as with the CU40/SH40 and SH51/52 systems. The sensor head will store the image by CCD line and not by time because post processing is more efficient with direct access to line images. Each CCD line will be stored continuously into CPU RAM and then distributed by the MMStorageAgent to fill the buffer at work before moving to the next buffer.

3.4 Software and Processing

The full effectiveness of the hardware improvements to the Leica ADS40 will be enhanced by a well-developed and integrated software package. Some modules, such as Flight Planning and Evaluation Software (FPES) and Leica FCMS module flight guidance were recently launched, whilst Leica FCMS ADS sensor control will be developed according to the concept in figure 5.

FPES optimizes the flight planning, provides quality control at an early stage of the flying project and delivers an output which is directly used and perfectly interfaced to Leica FCMS. Leica

FPES performs not only the technical aspects of a flight plan but serves as a project management tool by providing data for proposals and invoicing. It further populates a flight plan data base for the efficient handling of large projects and monitors project progress.

Leica FCMS release 2.2, was released in Spring 2008 and its enhancements include vector data and GCPs as backdrop, simplified pilot views and independent and optimized pilot and operator views as well as flexible multi-language configurations. All data required for post-flight mission analysis is stored, a practical feature for large projects flown with more than one aircraft.

Until now, Leica FCMS has managed the flight and has controlled and configured the sensor system without direct interaction with generated image data. This should change with the new concept, as within Leica FCMS a separate application will manage the image and position data storage. The FCMS application will retain its three layer architecture. The FPM digital board will be connected to the CU through a PCIe board which will transport FPM digital board communication, image data, configuration and statistical data, PAV gyro-stabilized mount communication, PAV gimbal data and time tagged PPS messages.
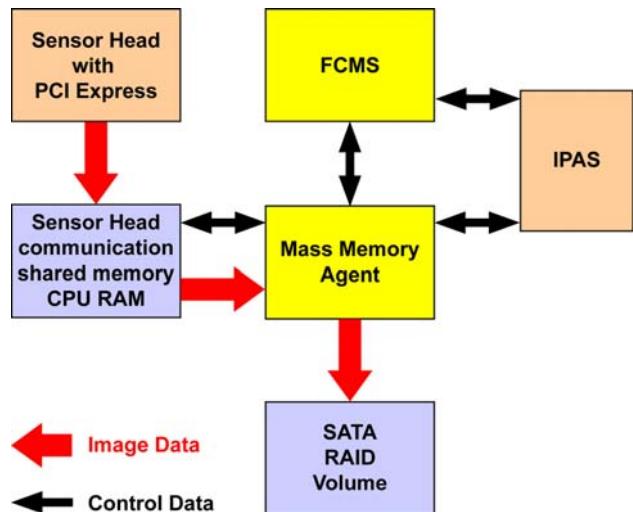

Figure 5. Software implementation in the new system centered on FCMS, IPAS and MMStorageAgent applications

3.5 Leica FCMS Hardware

The hardware components of the Leica FCMS are the Operator Interface OI40, OC50 for Pilot and the Guidance Indicator GI40. These various user interfaces use standard off-the-shelf components whose form, size and functions have been optimized for the specific applications. They can be duplicated in number and positioned at various locations within the aircraft where necessary for multi-sensor and multi-operator use. These reliable, high quality devices conform to ISO 7137, RTCA DO-160E, EUROCAE-14E and FAR§23.561 standards.

3.6 Image data processing

Image data processing applications are outside the scope of this paper but it is worthwhile to mention the following points to round off the improved Leica ADS40 system concept.

Tests have been done in [2] using Precise Point Positioning (PPP), a post-processing technique allowing high accuracy position and velocity determination using data from a single airborne Global Navigation Satellite System (GNSS) receiver to georeference the imagery. The results showed that with the choice of precise orbit and clock data and by using datum and IMU misalignment estimates in the aerial triangulation, a high level of orientation accuracy is achievable. This breakthrough allows users to eliminate ground referenced GPS receivers and to make imagery gathering in remote or dangerous areas more economically viable.

Geometric calibration parameters of the SH51/52 sensor heads include the modeling of the basic optical-mechanical properties of the lens and focal plane, the view angles of the 3-line imagery and the IMU misalignment. These sensor parameters are determined within the calibration process using bundle adjustment with self-calibration technology. The complete process of image capture required for the calibration and the calibration itself can be performed by the user without special knowledge and the method is assisted by an automatic weighting process for additional observations in the ORIMA software.

4. ATTITUDE AND POSITION MEASUREMENT SYSTEMS

4.1 IMU Inertial Measurement Unit

Mechanical improvements to the basic design of the Leica ADS40 as realized in SH51/52 resulted in a more compact and geometrically stable integration of the IMU platform above the optical axis. This extends not only the range of compatible IMU units, but facilitates the IMU exchange by the user himself.

Leica Geosystems have recently released the new Leica IPAS20, which consists of the Leica IPAS20 Control Unit with integrated GNSS receiver, GNSS antenna, IMU and software. Leica IPAS20 will also become an embedded part of the improved Control Unit for the Leica ADS. Leica IPAS provides an interface to the Leica FCMS. The IMU interface provides a connection to the best choice of IMU for a particular sensor and application. The IMU selection criteria are based on user requirements for performance, accuracy and cost. The available

IMUs of different accuracy classes and manufacturers have passed Leica's qualification process. In addition to GPS, Leica IPAS20 also tracks GLONASS satellites and an upgrade to GPS L5 and Galilieo is planned once these systems become operational.

5. SUMMARY AND CONCLUSIONS

Leica Geosystems AG Airborne Digital Sensor solution continues to produce revolutionary results in image data collection and applications.

The strict adherence to the 3-line principle, combined with a unique sensor head design that maintains calibration over extreme long periods of time and the revolutionary Tetrachroid allow the generation of co-registered, highly accurate image strips of equal resolution in all bands. Further, the combination of new material and components with new data processing concepts will provide measurable cost-benefits to the users. Overall, the improvements to the ADS will increase productivity, reliability and ease of service and will ensure that the ADS owner continues to push the envelope of applications in both high-resolution photogrammetry and remote sensing.

The results will be that an excellent sensor will get even better!

REFERENCES

1. Tempelmann, U.; Hinsken, L. 2007. Hardware improvements of the ADS40 sensor heads SH51/52 and how they allow a better camera model for self-calibration; *Proceedings Optical 3D Measurements Symposium, Zürich*

2. Saks, T.; Tempelmann, U. 2008. ADS40 system with new sensor heads – key to the simplified model for self-calibration and extended user benefits; 2008. *EuroCOW, Spain*

3. Fricker, Peter; 2007. Raising the Bar for Multi-Band, High-Resolution Airborne Imagery. *Photogrammetric Week '07, Wichmann Verlag, Germany.*