

DIGITAL AERIAL CAMERAS

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ABSTRACT:

Airborne digital sensors are about to widen the choices in photogrammetry. The transition from analytical to digital photogrammetry is well advanced. Recent technology developments provide new solutions for high-resolution image acquisition for photogrammetric applications. These sensors are based on CCD-matrices as well as CCD-line sensors and fulfill both. The emphasis is placed on general problems of developing new sensor systems. The necessity of detailed information about their technical specifications, geometric evaluation, geometric models and also their advantages on analog photogrammetric cameras, at a very early stage of camera development has been proved.

1. INTRODUCTION

For a long time, images acquired from analog film and digitized by scanners were used for digital image processing purposes. Now digital cameras are replacing analog ones. They are two kinds: 1) Digital aerial Frame sensors can be handled in common digital photogrammetric work stations. 2) CCD-line sensors scan the same ground area with three or more panchromatic sensors at different angles to acquire forward, nadir and backward scenes. After the raw imagery and metadata are downloaded, determination of exterior orientation parameters and subsequent image rectification, enable stereo viewing in different possible geometric combinations. The well known advantage of digital cameras over film frame cameras is that film processing and scanning are not required. A big problem in their marketing is that their specifications and advantages are not always too apparent to the user. So this research focuses on the introduction famous commercial digital aerial sensors, their technical specifications, geometric models and their accuracy based on some performed investigations and possibility of using them in map production.

2. AIRBORNE DIGITAL SENSORS

Airborne digital cameras are based on large CCD-matrices as well

as CCD-line sensors. The first has geometry the same as analog cameras. The technology of second one has been used in Single or multi-line cameras for spaceborne sensors to provide high-resolution wide angle or even panoramic imagery.

2.1 Airborne matrix cameras

These matrix cameras have defined, rigid, central perspective image geometry and a simple interfacing to existing photogrammetric software. Based on the size of the array of detectors, they will be considered here under three main headings: small-format cameras (between 1 and 6 Megapixels), medium-format cameras (around 16 Megapixels) and large-format cameras (36 Megapixels or larger).

In multiband images production Single cameras (equipped with a mosaic filter, rotating filter wheels, three CCDs with a beam splitter) and multiple cameras (coupled together and equipped with the appropriate color filters) can be used for more information refer to (Petrie , 2003).

The most famous airborne matrix cameras are shown in figure 1. Their technical specifications exist in table 1. Till now available CCD arrays used in commercial digital airborne cameras are not so large. To extend the swath of the matrix camera, multiple camera heads are necessary. As you see in figure 2, DMC and UltraCam-D provide large format images by combination of multi images. DSS is small format camera. DiMAC has four independent cameras which can be combined in different ways.

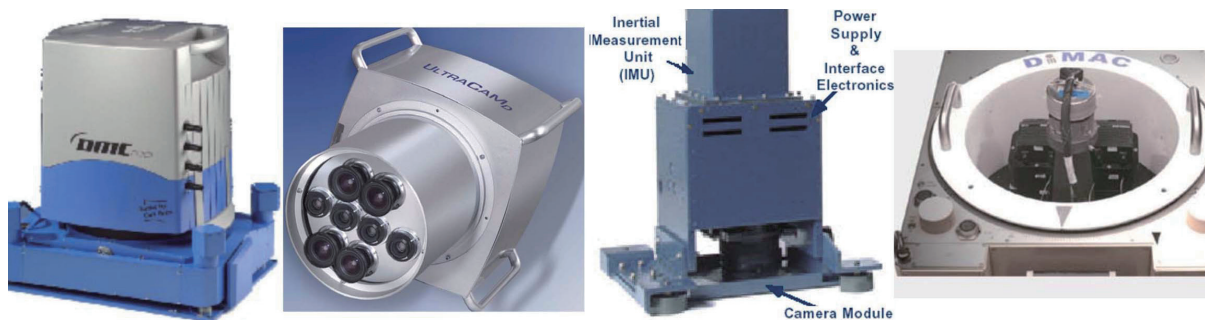


Figure 1: Airborne matrix cameras

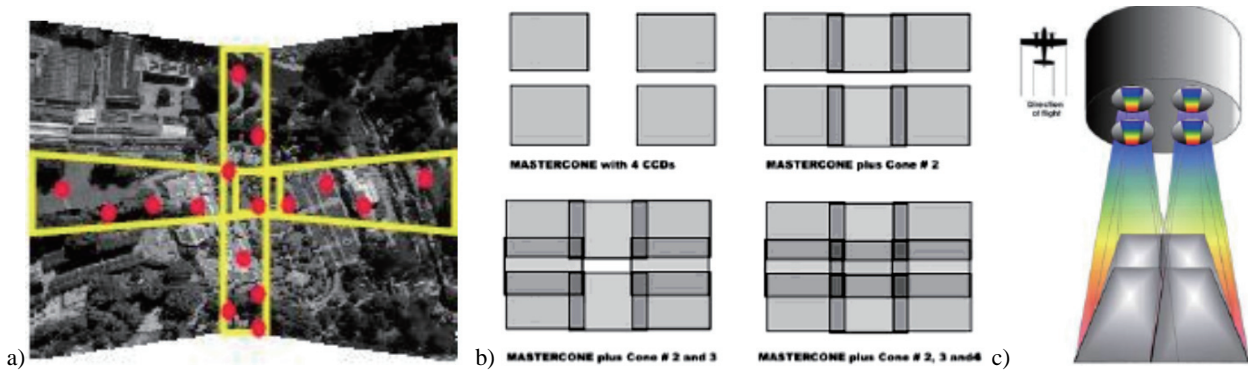


Figure.2: a)DMC and b) UltraCam-D large format images provided by combination of multi images. c) A combination of DiMAC independent cameras.

Table 1: Airborne matrix cameras specifications

Camera Parameter	DMC	UltraCam	DiMAC	DSS
Panchromatic Focal length (mm)	120	100	_____	_____
Multi spectral Focal length (mm)	25	28	60,80,100, 120, 150	55, 35
Pixel size (µm)	12	9	9	9
Panchromatic line (pixels)	13500 × 8000	11500 × 7500	_____	_____
Color lines (pixels)	3000 × 2000	4000 × 2700	5440 × 4080	4029 × 4077
Field of View	77 × 44	55 × 35	_____	55/4 ,37
Dynamic range	12	12	16	12
Imaging rate (frame/second)	2	1	0/5	0/4
Compatible GPS/IMU	POS/AV 510	Aerocontrol AC by IGI Applanix POS AV	Aerocontrol AC by IGI Applanix POS AV	Applanix POS/AV

2.2 Airborne pushbroom scanner

The various types of airborne mapping pushbroom scanners are panchromatic scanners, Multi-spectral scanners with multiple linear arrays designed to produce color or false-color images and 3-line scanners pointing to forward, nadir and backward. The third is used in the Leica ADS40 camera.

Larger sizes of linear arrays mean much higher cost. Linear arrays with up to of 14,400 pixels long are now on offer. These longer CCD arrays are supplied by various specialist manufacturers such as Kodak, Fairchild Imaging and Perkin-Elmer in the U.S.A.; E2V in the U.K.; Atmel in Grenoble, France (formerly owned by Thomson CSF) besides various facilities in the U.S.A.; Dalsa with manufacturing facilities in Canada and in the Netherlands, the latter formerly owned by Philips; and Sony in Japan. (Petrie, 2005)

Using *multiple linear arrays* to wide swath of the pushbroom scanner causes some difficulty in comprising butted CCDs together. To solve these problems there are some solution such as: a dual-lens to implement the wider swath or staggered but overlapping position linear arrays to give the required wider coverage by using a single optical mirror.

The manufacturer produces these in a standard length exist with a trade-off between detector size and the number of detectors in the array. (Table 2)

detector size (µm)	number of detectors in the array
5	14400
7	10200
9	8000
12	6000

The smaller-sized detectors have a smaller surface area available for collection of the radiation coming from the ground and this may require the use of larger aperture lenses to ensure a sufficient exposure. To increase the image resolution, paired linear arrays can be used, with each array offset by half-pixel relative to the other. This mode of imaging (Supermode) has been utilized the Leica ADS40 camera (Figure3).



Figure.3: Staggered CCD line arrays of ADS40

The most famous airborne pushbroom cameras are shown in figure 4. their technical specifications exist in table 3. The arrangement of line arrays for each of them are in figure 5.

Table 2: number of detectors in the array in relation with detector size (Petrie, 2003)



Figure.4: Airborne Linear Cameras: ADS40-HRSC-AX-StarImager

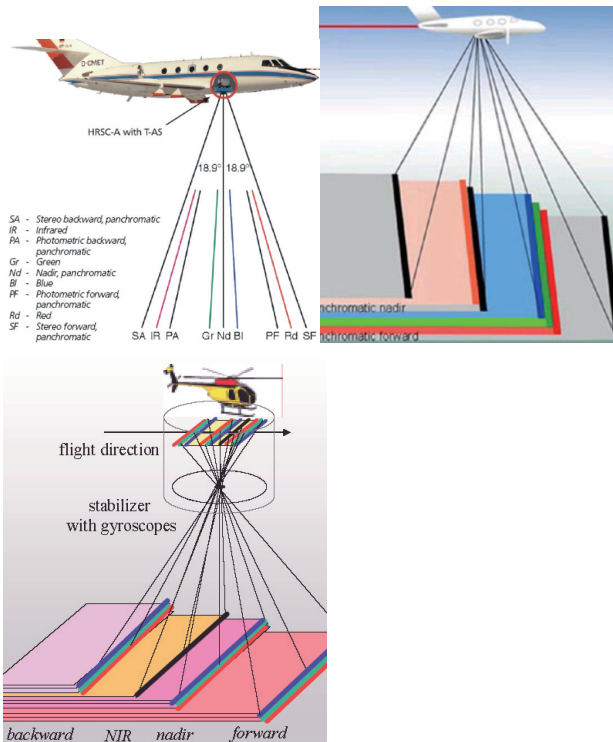


Figure.5: The Imaging in the first row ADS40, HRSC-AX and in the second StarImager

All line scanners need to be operated from a very stable imaging platform to avoid gaps and double imaging. Airborne platforms are unstable in comparison with spaceborne one. Unpredictable changes in the attitude and altitude of the platform decrease with the use of gyro-stabilized mounts but still substantial geometric displacements will remain. A single scanner image comprises many hundreds or thousands of discrete lines at different moments with different positions and attitudes. It is quite impractical to utilize a pushbroom sensor without *DGPS/IMU* system, for measuring very good estimates of the position of the projection centre and the corresponding set of attitude (tilt) values. The obligatory use of a *DGPS/IMU* system with a pushbroom line scanner increases the cost of the overall scanner system.

Table 3. Parameters of the Linear sensors

Camera parameters	ADS40	HRSC-AX	StarImager
Focal length (mm)	62.5	150	65
Pixel size (μm)	6.5	6/5	5
Panchromatic line (pixels)	2x12.000	12000	14400
Color lines (pixels)	12.000	12000	14400
Imaging rate (line/second)	830	1640	500

Field of View	64°	11/81° 37/8°	68°
Forward Stereo angles	28°	12/8	30
Backward Stereo angles	14°	20/5	20
FB Stereo angles	42°	33/3	51
Dynamic range	14 bit	12	11
Compatible GPS/IMU	Applanix POS AV	Applanix POS AV	Applanix POS AV or other DG systems

3. THE GEOMETRICAL MODELS

These mathematical models describe the transformation of a point from the image coordinate system to the ground coordinate system. The most famous 3 dimensional model is collinearity equations.

3.1 The geometrical model of matrix cameras

These cameras have central perspective geometry like analog cameras and the mathematical models are the same. But in some large format digital frame cameras we use composite of several images like DMC and UltraCam-D. At the top of Figure 6 you can see the projection center of composition of DMC in relation with backward and forward views. The bottom of this figure shows composite image in red and its component in black.

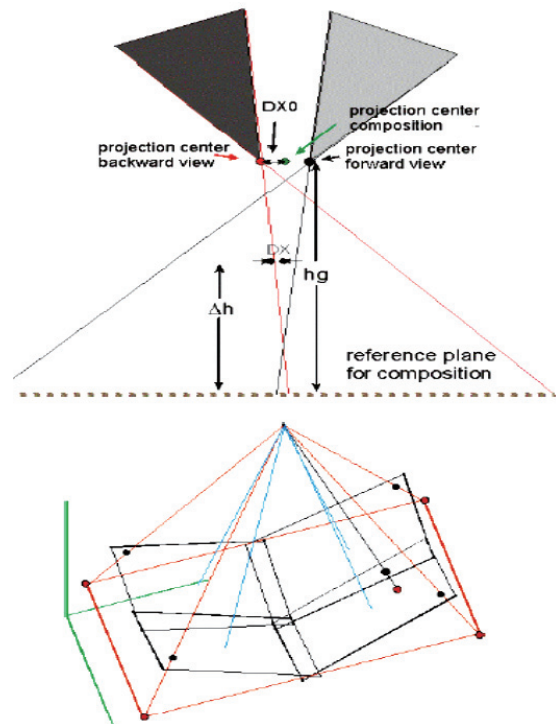


Figure6. Ground coverage of 4 head camera system

Resulted image is compatible with existing photogrammetric procedures and software. The post processing to form the composite (virtual) image includes the following tasks for every image exposure:

- Mounting angles of the panchromatic heads are determined by a bundle block adjustment technique (= “platform calibration”)
- corrected image coordinates after The laboratory calibrations of the single camera heads are used in this step.
- Transformation parameters using the four sets of exterior orientation parameters are computed to map from the single images to the virtual image.
- The single panchromatic images are projected to the high resolution virtual image using the computed transformation parameters.

To composite images accurately: (a) all raw images must be acquired synchronously in time, (b) the systematic effect resulting from the different perspective centers must be negligible, and (c) the relative orientation of the camera heads must be stable (Madani, Dörstel, Heipke, Jacobsen, 2004).

So to achieve accurate virtual image, Releasing the shutters of the camera heads with a precision of less than 0.01 msec is required. Systematic displacement of the generated central perspective image composite requires the exact knowledge of the height of each point on the ground that is not generally available; the horizontal reference plane is used as an approximation instead. Thus, there is a residual relief displacement effect, depends on the height variation in object space to the flying height above the ground. Tang showed that the resulting error in the central perspective image composite could be neglected, even for very high accuracy requirements if the height variation is not extreme. (Tang, Dörstel, Jacobsen, 2000)

3.2 The geometrical model of pushbroom cameras

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. (Fricker, 2001)

To utilize the GPS/IMU exterior orientation values without triangulation, the coordinate transformation between the GPS/IMU system and the photogrammetric system must be known. The axes of the gyro system which represent the axes of the IMU cannot be perfectly aligned with the axes of the photogrammetric system and GPS antenna centre doesn't coincide with the projection centre. The remaining misalignment and offset is determined by the bundle adjustment roughly which divided into 2 stages:

- The analysis of GPS/IMU data process: the exterior orientation parameters are calculated from the position and attitude of the airplane at the time of image capturing.
- The block adjustment: the accuracy of the block is improved by simultaneous bundle adjustment with the exterior orientation parameters from the former process and tie point by automatic point measurement. Furthermore, by the adjustment with self-calibration and ground control point, systematic error between GPS/IMU, sensors and systems are also adjusted simultaneously.

The number of unknown would be too large with respect to GPS/IMU system data collection rate, a large number of Ground Control Points (GCPs) and Tie Points (TPs) is required. For this reason the main problem for CCD linear scanners georeferencing is to define a suitable time dependent function for example Lagrange Polynomials with variable orientation fixes that models the exterior orientation. (Figure7)

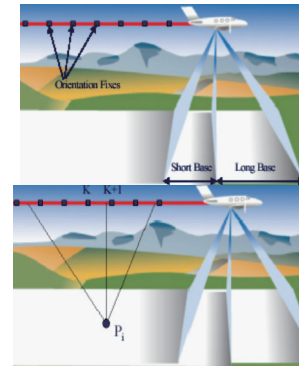


Figure.7: Orientation fixes that are used to model the exterior orientation

The image coordinates are expressed as a function of the ground point (P_i) and the orientation parameters of the two neighbouring orientation fixes (k) and ($k+1$). The mathematical model is given in full detail by Müller (1991).

$$x_i = F(X_i, Y_i, Z_i, X_k, Y_k, Z_k, \omega_k, \varphi_k, \kappa_k, X_{k+1}, Y_{k+1}, Z_{k+1}, \omega_{k+1}, \varphi_{k+1}, \kappa_{k+1})$$

$$y_i = G(X_i, Y_i, Z_i, X_k, Y_k, Z_k, \omega_k, \varphi_k, \kappa_k, X_{k+1}, Y_{k+1}, Z_{k+1}, \omega_{k+1}, \varphi_{k+1}, \kappa_{k+1})$$

The orientation parameters (X_j, κ_j) are computed from their neighboring orientation fixes plus a correction term ($\delta X_j, \delta \kappa_j$) derived from the GPS/IMU observations. The interpolation coefficients (c_j) are a function of the time differences from the neighboring orientation fixes. (Hinsken, Miller, Tempelmann, Uebbing, Walker, 2001)

$$X_j = c_j X_k + (1 - c_j) X_{k+1} - \delta X_j$$

$$\dots$$

$$\kappa_j = c_j \kappa_k + (1 - c_j) \kappa_{k+1} - \delta \kappa_j$$

$$c_j = \frac{t_{k+1} - t_j}{t_{k+1} - t_k}$$

$$\delta X_j = c_j X_k^{GPS} + (1 - c_j) X_{k+1}^{GPS} - \delta X_j^{GPS}$$

$$\dots$$

$$\delta \kappa_j = c_j \kappa_k^{GPS} + (1 - c_j) \kappa_{k+1}^{GPS} - \delta \kappa_j^{GPS}$$

Finally the orientation parameters (X_j, κ_j) are introduced into the well known collinearity equations to transform the point from the ground system to the sensor system.

4. DIGITAL IMAGING OPPOSITE TO ANALOGUE IMAGING

4.1 The usefulness of digital and analogue imaging systems

The comparison between digital and film-based data is done taking into account photographic and photogrammetric issues. Not only radiometric quality, but also the geometric performance of digital and analog cameras is investigated. In comparison of the quality and the information content of panchromatic digital images versus analog film, different film types and a digital sensor and their output have been investigated by Perko and Gruber. Some criterias like noise, edge response, image matching and Siement test have been used for measuring image quality. The results tell that digital image quality is more. (Perko, Gruber, 2002)

4.2 The cost of digital imaging in comparison to analogue imaging

Digital cameras in comparison to analog ones have only the fixed costs of the digital system; no additional costs per image exist (with the exception of additional flying time if

60% side-laps are used). What differs in using analog cameras is the cost for: film, photo processing, certain labor such as scanning and film management, maintaining a photo lab and a film archive. Based on surveys in US using digital imaging technology for mapping of large area is more economic in relation to analogue imaging. (Leberl, Thurgood, 2004) So a very important advantage is the ability to increase overlaps freely.

4.3 Geometrical evaluations of digital cameras

Images of these cameras have been analyzed and tested in different areas. In these investigations of digital aerial cameras good results achieved (Table.5) and the ability of them in large scale map production (with respect to their high radiometric quality) have been proved.

Table.5: Horizontal and vertical accuracy of digital cameras

Camera parameters*	ADS40 ¹	StarImager ²	DMC ³	UltraCam ⁴	DiMAC ⁵	DSS ⁶
Pixel size (µm)	6/5	5	12	9	9	9
Scale	32000	30000	13000	15000	16667	20000
Ground Pixel size (m)	0/2	0/15	0/156	0/135	0/15	0/18
Horizontal accuracy (m)	0/17	0/10	0/036	0/12	0/07	0/16
Vertical accuracy (m)	0/27	0/19	0/06	0/39	0/06	0/22

5. CONCLUSIONS

With respect to this brief we can count the benefits of digital aerial cameras as follows:

- Black and white, color and false color images without extra charge.
 - Digital sensors –high radiometric quality, high signal-to-noise ratio and linear response to incoming radiation provide detailed information for image interpretation.
 - More coverage and more redundancy – ideal for image matching as well as stereoscopic viewing.
- Insufficient redundancy is the major reason that automatically created Demos using stereo matching of scanned film images have significant errors and miss data, and occlusions due to a lack of redundancy are the major limitation of orthophoto products.
- Reduced ground control owing to tight integration of focal plate, IMU and GPS and the complete absence of film errors.
 - End-to-end digital flow line — no chemical film processing or scanning.
 - High quality DTMs from stereo sensor data.
 - Smooth data flow.
 - More geometric accuracy
 - Quality control during flight

In addition, map production cost will decrease with digital camera. So we can say map production with these cameras will be faster, easier, cheaper with more quality. There is very clear trend to digital cameras because of these obvious advantages that causes the fast development of this technology. So replacing of analog aerial cameras by digital aerial cameras is predictable.

6. REFERENCES

- Alhamlan, S., Mills, J.P., Walker, S.S., Saks, T, 2004: The Influence of Ground Control Points in the Triangulation of Leica ADS40 Data, ISPRS Congress, Istanbul 2004 IntArchPhRS. Vol XXXV, B2.
- Fricker P., 2001. ADS40 – Progress in digital aerial data collection. Photogrammetric Week '01, Wichmann Verlag, Heidelberg, pp. 105 - 116.
- Hinsken L., Miller S., Tempelmann U., Uebbing R., Walker S., 2001. Triangulation of LH Systems' ADS40 imagery using ORIMA GPS/IMU. International Archives of

Photogrammetry and Remote Sensing, Vol. 34, Part B3/A, pp. 156-162.

- Leberl, F; Thurgood, J., 2004. The Promise of Softcopy Photogrammetry Revisited. International Archives of Photogrammetry and Remote Sensing, pp. 1051-1057.
- Ip, A.W.L., Mostafa, M.M.R, El-Sheimy, N. 2004. Fast Orthophoto Production Using The Digital Sensor System. Proceedings of the 7th Annual International Conference – Map India 2004, New Delhi, India, January 28-30.
- Madani, M., Dörstel, C., Heipke, C., Jacobsen, K., 2004: DMC Practical Experience and Accuracy Assessment, ISPRS Congress, Istanbul 2004 IntArchPhRS. Vol XXXV, B2. pp396-401
- Perko, R. and Gruber, M., 2002. Comparison of quality and information content of digital and film-based images. ISPRS Commission III: Theory and Algorithms XXXIV(3B), pp. 206–209.
- Petrie G. (2003) Airborne Digital Frame Cameras - The Technology is Really Improving. GeoInformatics, Vol. 6, No. 7, 18-27.
- Petrie G. (2005) Airborne Pushbroom Line Scan - The Technology is Really Improving. GeoInformatics, Januari/Februari 2005
- Smith, M. J. a; Qtaishat, K. S. a. 2004. Initial results from the Vexcel UltraCam D digital aerial camera. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Commission I, WG I/1
- Tang, Liang; Dörstel, Christoph; Jacobsen, Karsten., 2000 Geometric accuracy potential of the digital modular camera. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, pp 1051-1057.
- Tsuno K., Murai S., Shibasaki R., 2004. StarImager – A new airborne three-line scanner for large scale applications. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 35, Part B1, pp.226-234
- www.dimacsystems.com technical articles: test_flight_for_accuracy.pdf
- www.dimacsystems.com technical articles: technical_specifications.pdf

* 1. (Alhamlan, Mills, Walker, Saks, 2004)
 2. (Tsuno, Murai, Shibasaki, 2004)
 3. (Madani, Dörstel, Heipke, Jacobsen, 2004)
 4. (Smith, Qtaishat, 2004)
 5. (test_flight_for_accuracy.pdf of dimacsystems)
 6. (Ip, Mostafa, El-Sheimy, 2004)