Digital Large Format Airborne Cameras

Tomislav CICELI, Dubravko GAJSKI

University of Zagreb, Faculty of Geodesy, Chair of Photogrammetry and Remote Sensing
Kačićeva 26, 10000 Zagreb, Croatia

Abstract:*The paper presents current situation of technologies in the field of airborne digital large format cameras. Design of different cameras is detailed described with their specificities.*

Key words: *photogrammetry, digital airborne camera, CCD*

1 Introduction

At the ISPRS congress which took place in Amsterdam in 2000 the first commercial solutions of digital airborne cameras were introduced. From that day on, there are more than 150 operational systems of large airborne cameras available in the world market. In the meantime, some of manufacturers offered more sophisticated solutions of their existing cameras (Vexcel, Leica, DiMac System).

The advantages of digital airborne cameras over film cameras are:

- Better radiometry
- Cost savings on films, developing and scanning
- Faster and quicker distribution of recorded materials. With GPS and IMU support oriented images can be delivered with plane landing.

When we speak about large airborne cameras we mean cameras then can be compared with classical film cameras with image format of 23 cm × 23 cm, and they produce images with more than 50 megapixels in size. It can be see in the table 3 that direct comparison is not possible because such a big sensor is still not available. In this field there are few different solutions available, and they will be analyzed.

2. Situation on the Market

Development of technologies brings different solutions, but generally speaking, we have three main approaches in design of digital airborne cameras today:

- Combination of few medium format sensors the images of which are in post processing merged into one. This approach is used by DMC (Intergraph Corp.), UltracamD and UltracamX (Vexcel Corp.) and DiMac (DiMac System)
- Cameras based on line sensors. Representatives of this approach are Leica with it's ADS40, and The High Resolution Stereo Camera (HRSC) developed by the German Aerospace Center (DLR) for Mars mission
- One frame sensor. Representative is CAF 261 by Recon Optical.

All listed systems are based on *Charge Coupled Devices* (CCD) sensors. We can expect that large format airborne camera based on *Complementary metal–oxide–semiconductor* (CMOS) sensors will appear in the near future.

The market of digital airborne cameras exists for a relatively short period of time, so it is expected that a number of new solutions will appear from companies that were not involved in producing analogue airborne cam-

Digitalne aerokamere velikog formata

Tomislav CICELI, Dubravko GAJSKI

Geodetski fakultet Sveučilišta u Zagrebu, Katedra za fotogrametriju i daljinska istraživanja
Kačićeva 26, 10000 Zagreb

***Sažetak:** Rad opisuje trenutačno stanje tehnologije na području digitalnih aerokamera velikog formata. Detaljno su opisane izvedbe kamera sa svim svojim posebnostima.*

***Ključne riječi**: fotogrametrija, digitalna aerokamera, CCD*

1. Uvod

Na kongresu ISPRS-a 2000. godine u Amsterdamu predstavljena su prva komercijalna rješenja digitalne aerokamere. Od tada do danas operativno je više od 150 sustava kamera ''velikog formata''. U međuvremenu su neki od proizvođača ponudili tržištu i dorađene verzije postojećih rješenja (Vexcel, Leica i DiMac System). Prednosti digitalnih kamera nad analognima su sljedeće:

- Bolja radiometrijska svojstva
- Ušteda na cijeni, razvijanju i skeniranju filmova
- Brža i jednostavnija distribucija snimljenog materijala. Uz potporu GPS-a i inercijalnih sustava moguće je već prilikom slijetanja aviona, nakon obavljenog zadatka, imati orijentirane snimke.

Pod kamerama velikog formata podrazumijevaju se kamere koje se svojim svojstvima (ponajprije veličinom snimke) mogu usporedit s analognim aerokamerama formata snimke 23 cm × 23 cm, te stvaraju snimku rezolucije bolje od 50 megapiksela. Kako se vidi iz tablice 3 izravna usporedba nije moguća, jer senzor tih dimenzija još nije dostupan. Na tom području postoji nekoliko različitih rješenja koja će u nastavku biti podrobnije analizirana.

2. Stanje na tržištu

Razvoj tehnologije donosi i različita rješenja, no danas se uglavnom primjenjuju tri pristupa u izvedbi digitalnih aerokamera:

- Kombinacija od nekoliko senzora koji u naknadnoj obradbi čine jednu snimku. To su sljedeće kamere: DMC (Intergraph), UltracamD i UltracamX (Vexcel Corp.) i DiMac (DiMac System).
- Kamere utemeljene na linijskim senzorima. Predstavnici su Leica sa svojom kamerom ADS40, te kamera razvijena u Institutu za istraživanje planeta Njemačkog svemirskog centra DLR, Njemačka, za potrebe snimanja površine Marsa pod oznakom HRSC.
- Jedan površinski senzor. Predstavnik je CAF 261 (Recon Optical).

Svi navedeni sustavi temelje se na CCD senzorima (*engl. Charge Coupled Device*). Očekuje se da će se u skorijoj budućnosti pojaviti i digitalne aerokamere ''velikog formata'' temeljene na CMOS tehnologiji (*engl. Complementary Metal Oxide Semiconductor*).

Tržište digitalnih aerokamera relativno je kratkog vijeka, pa se očekuje veći broj novih rješenja proizvođača koji do sada nisu izrađivali kamere za fotogrametrijska snimanja. Međutim ta će rješenja vjerojatno ići u smjeru razvoja i uporabe digitalnih aerokamera manjeg i srednjeg formata (Petrie, 2003).

eras and equipment. These solutions will probably be oriented toward developing and usage of small and medium format frame cameras (Petrie, 2003).

The major producers in the analogue camera market have been Leica and Zeiss (today Z/I Imaging) with aprox. 2000 sold camera systems from 1956 until today. Around 850 systems are still operational (Cramer, 2005). With the appearance of digital technologies it is expected that a new market will appear; the market of used analogue airborne cameras.

Current status by implemented digital camera systems in the market is listed in table 1.

Table 1. Current situation in the digital airborne camera market, December, 2006

Type	Number of implemented systems in 2005[1]	Number of implemented systems in 2006[2]	Available in the market from:
ADS40 / Leica	27	46	2001
DMC / Intergraph	22	50	2003
UltracamD / Vexcel	19	47 (42 operational)	2003

[1] According to (Cramer, 2005)
[2] According to (Ciceli, 2007)

From Table 1 it can be seen that current status involves approximately around 150 operational camera systems. If we compare results from 2005 and 2006, it is obvious that the growth of digital camera market is rather big. The most likely reasons are:

- Staying competitive in the market by turning to new technologies
- Advantages of these technologies
- Tendency to complete automated process of photogrammetric workflow
- Bigger and bigger need for spatial data which are used in different applications for wider "non professional" users like "Google Earth" and "Virtual Earth".

From some time digital cameras are also present in Croatia.

3 Design of Digital Airborne Cameras

There are three main approaches in design of large airborne cameras. It is interesting to notice that digital frame cameras are rarely based (especially for civil purposes) on only one sensor. Usually it is a combination of few sensors or it is a line sensor. In Table 2 the main characteristics of currently available large format airborne cameras are shown.

The main difference between frame and line sensors in creating an image can be seen on Fig. 1.

3.1 Large frame sensors

The appearance of the cathode ray tube in 1897 made taking pictures possible for the first time with non photographic methods, but until 1923 it was impossible. At that year the first camera tube was patented, and it could be used for collecting images. Thus, the era of *non photographic methods* started in photography (Ciceli, 2004).

The main difference between digital and analogue camera lies in the media for light registration (Fig. 2). It is no longer a film, and we do not speak about photographic way of light registration. We are using sensors that are trying to simulate human vision and recognition using photoelectric effect.

Table 2. Main characteristics of currently available digital large format airborne cameras

Company	Model	Type	Format size	Number of sensors	Number of pixels by axis (size in mm)	Pixel size	Focal length
Z/I Imaging	Z/I DMC	Frame	Large	8 (4Pan, RGB, IR)	8000 × 14000 (96mm × 126mm)	12 µm	120mm
Vexcel	UltraCamD	Frame	Large	8 (4Pan, RGB, IR)	7500 × 11500 (67.5mm × 103.5mm)	9µm	100mm
Vexcel	UltraCamX	Frame	Large	13 (9Pan, RGB, IR)	9420 × 14430 (67.5mm × 103.5mm)	7.2µm	100mm
Leica	ADS40	Pushbroom or Line	Large	8 or 12 sensors in line	12000 in one line (78mm × ?)	6.5µm	62.5 mm
DIMAC Systems	DIMAC	Frame	Medium-Large	1-4 (modular)	5412 × 7216 (10500 × 7200, size for 2 sensors) (49.1 mm × 36.8mm)	6.8µm	55mm – 120mm

Na tržištu analognih kamera najznačajniji proizvođači su Leica i Zeiss (danas Z/I Imaging) s 2000 prodanih aerokamera od 1956. do danas. Pretpostavlja se da je danas operativno oko 850 analognih kamera (Cramer, 2005). Pojavom digitalnih tehnologija očekuje se da će se stvoriti novo tržište, ali ovaj put polovnih analognih kamera. Prema broju implementiranih digitalnih aerokamera trenutačno je stanje na tržištu prikazano u tablici 1.

Tablica 1. Stanje na tržištu digitalnih kamera; prosinac, 2006.

Proizvod	Broj implementiranih sustava 2005[1]	Broj implementiranih sustava 2006[2]	Na tržištu od:
ADS40 / Leica	27	46	2001
DMC / Intergraph	22	50	2003
UltracamD / Vexcel	19	47 (42 operativno)	2003

[1] Podaci prema (Cramer, 2005.)
[2] Podaci prema (Ciceli, 2007.)

Iz tablice 1. vidljivo je da danas na tržištu postoji otprilike 150 operativnih kamera velikog formata. Usporede li se rezultati za 2005. i 2006. godinu može se zaključiti da je trend rasta tržišta digitalnih aerokamera popriličan. Najvjerojatniji su razlozi tomu:

- Održanje konkurentnosti na tržištu prelaskom na nove tehnologije
- Prednosti koje te tehnologije donose
- Težnja potpunoj automatizaciji fotogrametrijskog procesa realizacije zadataka
- Sve veća potreba za prostornim podacima koji se koriste u različitim aplikacijama za široki krug ‘‘neprofesionalinih’’ korisnika poput Google Earth, Microsoft Virtual Earth i sl.

U Hrvatskoj su digitalne aerokamere također odnedavno prisutne.

3. Građa digitalnih aerokamera

Kao što je već prije navedeno, postoje tri osnovna trenda u izvedbi kamera velikog formata. Zanimljivo je da se kod kamera matričnog tipa senzora rijetko (pogotovo u civilne svrhe) koristi samo jedan senzor, najčešće je riječ o nekoliko njih ili o određenom broju linijskih senzora. U tablici 2. prikazani su osnovni parametri aktualnih modela digitalnih mjernih aerokamera.

Osnovna razlika u nastajanju snimke može se vidjeti na slici 1.

3.1 Matrični senzori velikog formata

Pojavom katodnih cijevi 1897. godine otvara se prva mogućnost snimanja objekata nefotografskim postupcima, ali je to bilo neostvarivo sve do 1923. Tada je izrađena i usavršena prva cijevna kamera, kako bi se mogla koristit za prikupljanje snimki. Time počinje era *nefotografskih* postupaka u fotografiji (Ciceli, 2004).

Razliku između digitalne i analogne kamere predstavlja medij za registraciju svjetla (slika 2). To više nije film i više se ne govori o fotografskom načinu registracije svjetla. Za tu svrhu koriste se senzori koji pokušavaju simulirati ljudski vid i prepoznavanje koristeći fotoelektrični efekt.

Digitalna kamera svojim je glavnim dijelovima gotovo identična analognoj kameri. Razlika je u senzoru, koji po svojoj izvedbi može biti CCD ili CMOS te spremanju snimke na magnetske medije različitih memorijskih kapaciteta.

Tablica 2. Osnovne karakteristike trenutačno aktualnih modela digitalnih aerokamera velikog formata

Proizvođač	**Model kamere**	**Tip kamere**	**Veličina formata**	**Broj senzora**	**Broj piksela po osima u ravnini snimke**	**Veličina piksela**	**Žarišna daljina**
Z/I Imaging	Z/I DMC	Matrična	Veliki	8 (4Pan, RGB, IR)	8000 × 14 000 (96mm × 126mm)	12 μm	120 mm
Vexcel	UltraCamD	Matrična	Veliki	8 (4Pan, RGB, IR)	7500 ×11 500 (67,5mm × 103,5mm)	9 μm	100 mm
Vexcel	UltraCamX	Matrična	Veliki	13 (9Pan, RGB, IR)	9420 × 14 430 (67,5mm × 103,5mm)	7,2 μm	100 mm
Leica	ADS40	Linijska	Veliki	8 ili 12 senzora u liniji	12 000 u jednoj liniji (78mm × ?)	6,5 μm	62,5 mm
DIMAC Systems	DIMAC	Matrična	Srednji-veliki	1-4 (modularna građa)	5412 × 7216 (10 500 × 7200, veličina za 2 senzora) (49,1 mm × 36,8mm)	6.8 μm	55 mm – 120 mm

Table 3. Description of a few available large CCD sensors acceptable for photogrammetric purposes

Manufacturer	Model	Physical format (mm)	Resolution (Megapixels)	Pixel size (μm)
KODAK	KAF-39000	50.7 mm × 39.0 mm	7216 × 5412 (39MP)	6.8
DALSA	FTF5066M	35.9 mm × 48 mm	4992 × 6668 (33MP)	7.2
FAIRCHILD IMAGING	CCD 595	80.64 mm × 80.64 mm	9216 × 9216 (85MP)	8.75

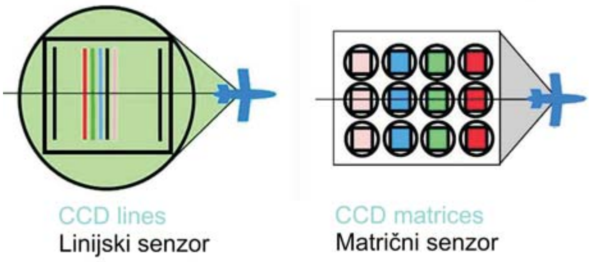


Fig. 1. The main difference between line and frame sensor in creating an image

Slika 1. Osnovna razlika u nastajanju snimke uporabom linijskog i matričnog senzora

In its main parts digital camera is almost identical to analogue camera. The difference is in sensor, which could be CCD or CMOS, and in storing images on magnetic media with different memory capacity.

All digital cameras are based on sensors. Vexcel and Z-I are using Dalsa frame sensors. Leica is using Atmel line sensor. Frame sensor made by Fairchild Imaging (Table 3) is twice as big as sensors used in available cameras, but it is still not available in commercial solutions. It is used for test purposes in the camera called *Ultra High Resolution Electro Optical Camera* (URL 2).

3.2 Multiple Sensors Cameras

If we speak about digital frame cameras, this is a dominant way of its realization. This is due to the price of such big sensors and hardware support needed for processing captured image from such a big sensor. Because of that companies have approached the problem with differently, and designed sets of multiple medium-format cameras coupled together to form an integrated unit with different geometry. Some companies[3] have cameras with modular number of cameras, and that number could be changed.

Fig. 3 and 4 show design and basic principle of two main cameras based on multiple number of CCD area arrays sensors.

[3] Dimac for example, in its first version of camera used four medium format cameras, and the latest model of camera is based on two medium format cameras that could be used together.

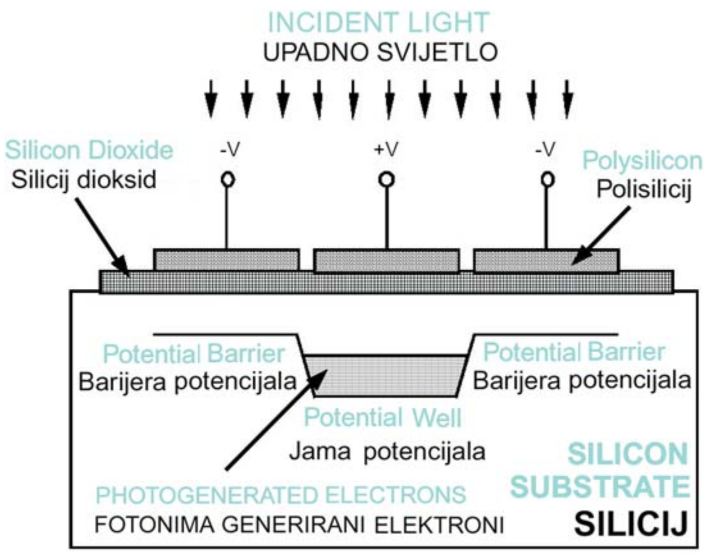


Fig. 2. Intersection of CCD sensor with potential well and potential barrier which surrounds the well (Eastman Kodak Company, 2001)

Slika 2. Presjek CCD-senzora s prikazom potencijalne jame i potencijalne barijere koja okružuje jamu te ne dopušta elektronima da se međusobno odbijaju (Eastman Kodak Company, 2001)

Tablica 3. Opis nekoliko trenutačno dostupnih CCD senzora velikih dimenzija pogodnih za fotogrametrijske namjene

Proizvođač	**Model**	**Fizička veličina**	**Rezolucija**	**Veličina piksela**
KODAK	KAF-39000	50,7 mm × 39,0 mm	7216 × 5412 (39MP)	6,8
DALSA	FTF5066M	35,9 mm × 48 mm	4992 × 6668 (33MP)	7,2
FAIRCHILD IMAGING	CCD 595	80,64 mm × 80,64 mm	9216 × 9216 (85MP)	8,75

Sve digitalne aerokamere temelje se na nekom od senzora. Vexcel i Z/I koriste se matričnim senzorima Dalsa. Leica se koristi linijskim senzorima tvrtke Atmel. Na tržištu postoji površinski senzor tvrtke Fairchild Imaging (vidi tablicu 3) koji svojim dimenzijama dvostruko nadmašuje senzore korištene u navedenim kamerama, ali nije dostupan u komercijalne svrhe (URL 1). Za sada je implementiran u testne svrhe u kameri pod nazivom *Ultra High Resolution Electro Optical Camera* (URL 2).

3.2 Kamere s većim brojem senzora

Taj način izvedbe digitalnih kamera dominantan je ako je riječ o digitalnim kamerama koje se temelje na matričnim senzorima. Razlozi tomu su u cijeni jednog velikog senzora odgovarajućih dimenzija, kao i o hardverskoj podršci koja bi bila nužna da se brzo preuzme registrirana snimka s jednog tako velikog senzora. Iz tih razloga proizvođači su pristupili drugačijem razmišljanju, te su osmislili digitalne aerokamere koje se sastoje od nekoliko senzora različite geometrije. Kod nekih proizvođača (npr. Dimac) kamera je modularne građe, te se broj senzora može mijenjati.

Na slikama 3 i 4 vidi se građa i principi nastajanja snimke kod dva tipa digitalnih aerokamera modularnog tipa koji se najčešće koriste.

Kod takvih tipova kamera snimka punog formata nastaje naknadnom obradbom (*engl. post processing*). Tim se postupkom sveukupno snimljena površina (koja je uvijek veća nego finalna snimka) obrađuje tako da se na osnovi zajedničkih točaka (nastalih postupkom triangulacije) u područjima preklopa između snimki izjednačavaju radiometrijska i geometrijska svojstva snimki, spajaju i na kraju produciraju kao jedinstvena snimka. Slika 5. prikazuje proceduru kod digitalne aerokamere Intergraph DMC.

3.3 Nastajanje boje u kamerama s matričnim senzorom

Jedna od osnovnih razlika između digitalne i analogne tehnologije nastanka slike je i proces nastajanja boje. Kod klasičnog filma boja nastaje registracijom informacije o boji u odgovarajućem sloju u samom filmu.

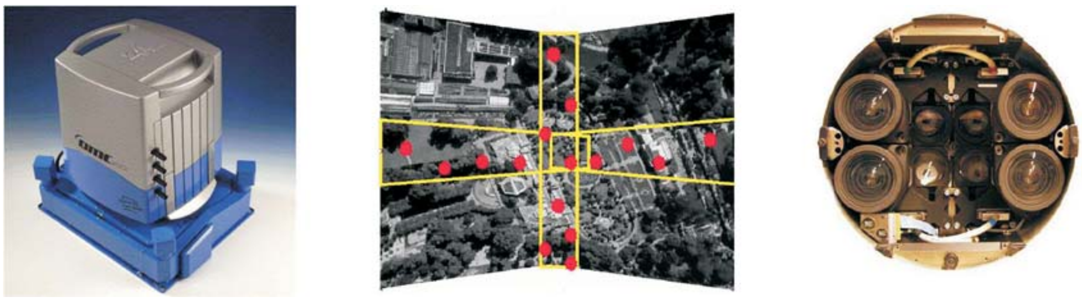


Fig. 3. Design and basic principle of creating an image using Intergraph DMC digital airborne camera

Slika 3. Prikaz građe i principa nastajanja snimke kod digitalne aerokamere Intergraph DMC

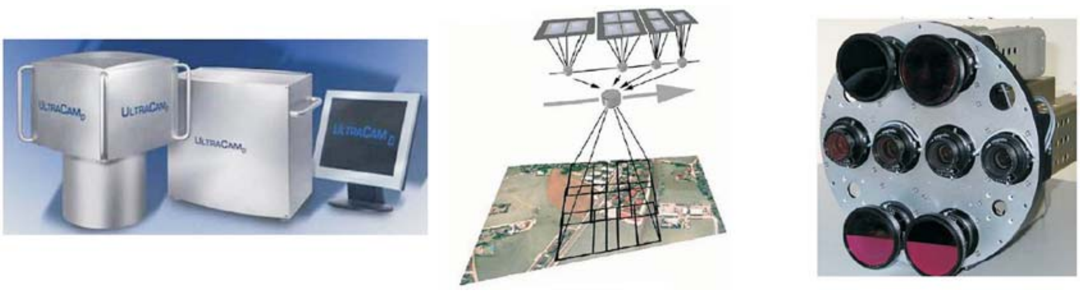


Fig. 4. Design and basic principle of creating an image using Vexcel UltracamD digital airborne camera

Slika 4. Prikaz građe i principa nastajanja snimke kod digitalne aerokamere Vexcel UltracamD

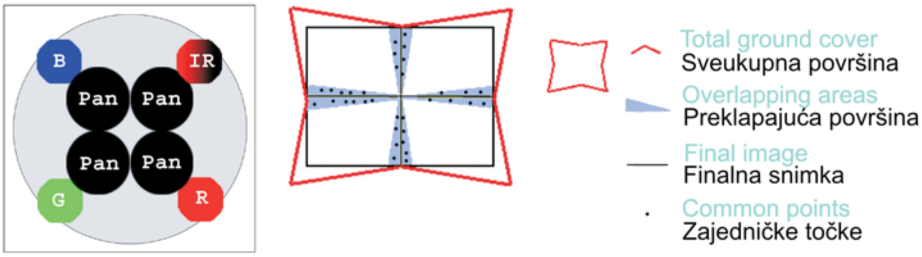


Fig. 5. Workflow of creating image on Intergraph DMC camera
Slika 5. Princip nastajanja snimke Intergraphovom kamerom DMC

Finally, full format image on cameras designed by this principle is created in post processing. With this procedure, complete taken field image (which is always bigger than final image) is processed using common points (created through process of triangulation) in areas of images overlap. In that area radiometric and geometric features of images are equalized, consolidated and produced like one image. Fig. 5 shows workflow on Intergraph DMC digital airborne camera.

3.3 Creating colour images in cameras with area sensor

One of the main differences between digital and analogue technologies in collecting images is in the way colour information is created. On a classic film, colour information is collected in the appropriate depth in the film.

By its nature CCD sensor is monochromatic, so it can not distinguish different parts of red, green and blue light. Because of that we have three different ways of collecting colour information:

1. Sequential Colour CCD
2. Three Chip Colour (3CCD sensor)
3. Integral Colour Filter Arrays.

Digital airborne cameras made by *Intergraph* and *Vexcel* are creating colour in artificial way. Four sensors are collecting information about colour: red, green, blue and infra red (Fig. 5) and there are separate sensors for collecting information in panchromatic mode.

Sensors for collecting information about colour have lower resolution (4 to 5 times) than panchromatic sensors. To create colour image with maximal resolution, the method known from remote sensing, so called *pan sharpening*, is used for associating panchromatic and colour images (Fig. 6).

3.4 Cameras with line sensor (or pushbroom cameras)

The second most used way for construction digital airborne cameras is based on the usage of line sensor. This type of camera is different from classical way of thinking about aerial photo as a square form with standard dimensions. Most popular representative of this type of camera is *Leica* with ADS 40 model (Fig. 7).

In the first part of this text, HRSC camera is mentioned. Originally it was built for Russian Space Mission Mars '96. After the unsuccessful launch in November 1996 the *Institute of Space Sensor Technology and Planetary Exploration* modified the camera. Based on that model, another version, the HRSC-AX was built for airborne high-resolution 3D-earth-reconnaissance and is still under further development (URL 3).

In order to create stereo effect, this type of cameras produce three overlapping strip images that are acquired simultaneously using forward-, nadir- and backward-pointing linear arrays.

Digital airborne cameras based on area sensor, as well as analogue cameras, use ground control points for exterior orientation, which is standard procedure in photogrammetry used for many years. If we try to orient images collected with line sensor in the same way, we will need several numbers of points for every collected line, which is impossible for practical reasons. Hence, GPS/Inertial systems are needed for orientation of all images (lines). Development of cameras based on line sensor is closely related to the development of *GPS/Inertial systems* which are joined with the camera. In post processing, lines are oriented, stitched and complete image is created, as it can be seen on Fig. 8.

3.5 Creating colours with cameras based on line sensor

One of the main differences between frame cameras and cameras based on line sensor is in the way colour information is created. On line sensor based cameras all three pieces of information about colour (red, green and blue) are collected in full resolution, like panchromatic images. Colour images have the same resolution as panchromatic images, so they should not be created using *pan sharpening* method.

4 Tests of Digital Airborne Cameras

Because of high geometric demands, digital airborne cameras are often put on different tests. These evaluations are usually forced either by manufacturers who wants to prove the quality of their systems, or by independent institutions, like universities and institutes, or, finally by the potential buyers of these systems.

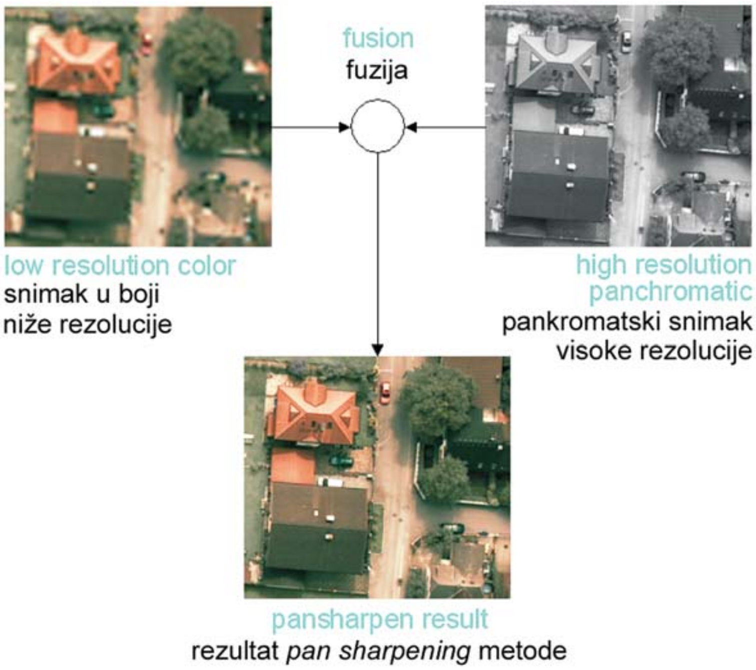


Fig. 6. Creating colour image using pan sharpening *method (URL 4)*

Slika.6. Nastanak snimke u boji (URL 4)

CCD-senzor po svojoj je naravi monokromatski, tj. nema sposobnost razlikovati različit dio crvenog, zelenog i plavog svjetla. Zbog toga se u industriji koriste tri osnovna načina za izdvajanje boje snimljene scene[3]:

1. CCD-senzor sa sekvencijskim dobivanjem boje
2. Tri CCD senzora
3. Integrirani filtri na samom senzoru.

Kod digitalnih aerokamera proizvođača Intergraph i Vexcel boja nastaje umjetnim putem. Četiri senzora predviđena su za registraciju informacije o boji: R, G, B i IR (infracrveni, kao što se može i vidjeti iz građe kamera) te posebnih senzora za prikupljanje informacije u pankromatskom načinu registriranja.

Senzori koji prikupljaju informaciju o boji niže su rezolucije (4 do 5 puta) od pankromatskih senzora. Kako bi se dobila snimka u boji maksimalne rezolucije potrebno je naknadnom obradbom, postupkom poznatim iz daljinskih istraživanja (*engl. Pan sharpening*), spojiti pankromatske snimke i snimke u boji (slika 6).

[3] CCD-senzor je još uvijek jedini prisutan kod digitalnih kamera velikog formata. Kod CMOS-tehnologije postoji i četvrti način, tehnologija Foveon X3 koja se ne će dodatno opisivati (Ciceli i dr., 2003)

3.4 Kamere s linijskim senzorima

Drugi, najčešće korišteni način za konstrukciju digitalnih kamera uporaba je linijskog senzora. Takav tip kamere odudara od klasičnog razmišljanja o aerosnimci kao pravokutnoj formi standardnih dimenzija. Najpoznatiji je predstavnik takvog tipa digitalne aerokamere Leica sa svojim modelom ADS 40 (slika 7).

U prethodnom dijelu teksta spomenuta je i kamera pod oznakom HRSC. Izvorno je razvijena za Rusku svemirsku misiju na Mars 1996. Međutim, nakon neuspjela lansiranja *Institut za senzorsku tehnologiju i istraživanje planeta* modificirao je kameru za potrebe *Mars Ekspres Misije* (*engl. Mars Express Mission*). Na temelju te kamere razvija se i kamera oznake HRSC-AX za snimanje iz aviona za potrebe prikupljanje 3D podataka visoke rezolucije (URL 3).

Fig. 7. Leica ADS 40 digital airborne camera based on line scanning

Slika 7. Leica ADS 40 digitalna aero kamera

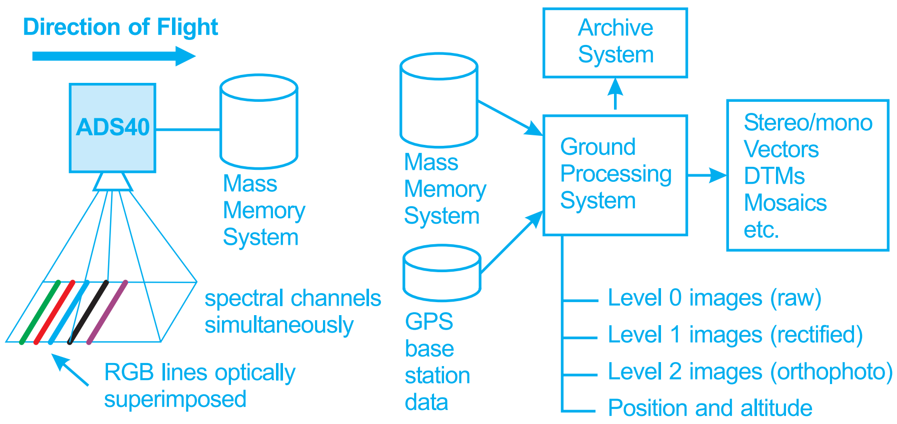


Fig. 8. Workflow of data collected with Leica ADS40 (Sandau et al. 2000)

The example of such a test field in Finland (Honkavaara et al. 2005.), for radiometric and spatial calibration of digital airborne systems is shown on Fig. 9.

Among other things, tests of digital airborne cameras have also been initiated by federal agencies or ministries, who have direct need for aerial images. Until now, the following countries have been initiators of tests: Sweden, Spain, Austria, Finland, Germany, USA, Switzerland and United Kingdom.

4.1 Experience and standardization of tests

Most overall test of all three main vendors of digital airborne cameras has been done by *EuroSDR network on Digital camera Calibration* (Cramer, 2004). Testing will be done in several phases, and test resolute will be available in Second phase of project, which is still in progress.

Standard procedure for camera testing still does not exist, and one of the reasons is a different approach in camera design. Currently, there are few initiatives for standardization of some procedures in process of using digital cameras.

In Germany, DIN (Deutsches Institut für Normung) is dealing with that. Currently, the fourth part of *Photogrammetric standards* is being completed. In the first three parts procedures for taking images with analogue airborne camera, scanning of images and procedure for creating orthophoto are described. In the fourth part, standards for digital airborne cameras will be done.

ISO with its ISO/TC 211 Geographic Information / Geomatics works on new raster standards.

4.2 Calibration

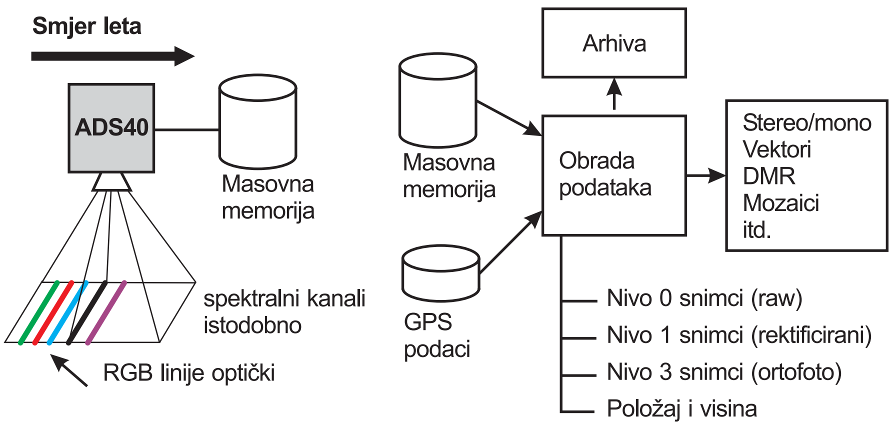
Calibration could be described as a procedure for defining system responses to known, controlled inputs, and determination of camera parameters which will enable the usage of digital images for measurements or interpretation. The calibration is done separately: for geometric characteristics and for radiometric characteristics.

The large-format photogrammetric analogue cameras are based on highly refined lens (e.g. the Pleogon [from Zeiss], Aviogon [Leica] and Lamegon [Jena]) with distortions that are very small (< 10µm) and highly symmetric, so that, for many purposes, they can be considered “distortion-free”. The values of inner orientation (the focal length (principal distance), the position of the principal point and the pattern of lens distortion) have been very accurately determined through a rigorous calibration procedure, and they are constant for long period of time. Taking images is based on central projection.

With the airborne digital imagers, the situation is sometimes very different. Because of the limited size of current CCD area arrays, multiple arrays of sensors are in use, in combination with multiple lenses. In a number of these digital imagers, lenses from commercial suppliers are being used rather than purpose-built lenses that have been optimized for photogrammetric purposes. Each of these multiple lenses will have slightly different inner orientation parameters (e.g. focal length and distortion pattern) (Petrie, 2006). Next main reason for taking care on camera calibration lies in the way images are created; stitching of few images (or lines on line scanner cameras) to a single large-format digital image. Because of that central projection, characterized for film camera, is lost. Besides all mentioned, the sensor, as a new medium for registration has its own rules of behaviour, which also has influences on the geometry of image. Result of all this is that calibration is a very important part of usage of digital cameras. It is so important, that all cameras have integrated solutions for performing inner orientation every time images are taken. But, because of instability of those parameters, classical calibration should be performed at least once a year.

Currently, there are a few organizations on global level which are dealing with calibration of digital airborne cameras:

1. ISPRS Commission I
2. CEOS (Committee of Earth Observing Satellites)
3. USGS (US Geological Survey) Digital Camera Characterization initiative
4. EuroSDR network on Digital camera Calibration.



Slika 8. Tijek obradbe rezultata nastalih snimanjem digitalnom aerokamerom Leica ADS40 (Sandau i dr., 2000)

Radi stvaranja stereoefekta kod takvih konstrukcija kamere postoji senzor koji skenira površinu ispred nadira, u nadiru i iza njega.

Kod digitalnih kamera s matričnim senzorom, kao i kod analognih kamera, orijentacija (vanjska) snimki provodi se uporabom orijentacijskih točaka na Zemlji, standardnim postupkom koji je uhodan i uobičajen dugi niz godina. Ako bi se pokušala istom metodologijom orijentirati snimka nastala linijskim senzorom, trebalo bi za svaku liniju imati određen broj orijentacijskih točaka, što je iz praktičnih razloga nemoguće. Zbog toga su za orijentaciju svih linija nastalih snimanjem potrebni GPS i inercijalni sustavi. Razvoj kamera s linijskim senzorom povezan je usko upravo s razvojem GPS i inercijalnih sustava koji su pridodani kamerama. U naknadnoj obradbi (engl. *post processing*) linije se orijentiraju, spajaju i na taj način se stvara snimka. Postupak se može vidjeti na slici 8.

3.5 Nastajanje boje u kamerama s linijskim senzorom

Jedna od osnovnih razlika između digitalnih kamera temeljenih na matričnim senzorima i linijskim senzorima je u procesu nastajanja snimaka u boji. Kod linijskih senzora sve tri informacije o boji (crvena, zelena i plava) prikupljaju se u punoj rezoluciji, kao i pankromatske snimke. Posljedica je toga da su snimke identične rezolucije poput pankromatskih, tj. ne nastaju umjetnim putem poput snimaka nastalih matričnim kamerama.

4. Testovi digitalnih aerokamera

Digitalne aerokamere su zbog svojih visokih zahtjeva prema geometriji vrlo često podvrgavane različitim testovima. Takve testove pokreću ili sami dobavljači, kako bi dokazali kvalitetu svojih sustava, ili neovisne institucije poput sveučilišta ili instituta, te na kraju i sami zainteresirani kupci.

Primjer jednoga takvog test-polja u Finskoj (Honkavaara i dr., 2005) za radiometrijsku i prostornu kalibraciju digitalnih aerosustava za snimanje prikazan je na slici 9.

Testove digitalnih aerokamera do sada su, među ostalim, potencirale i državne agencije ili ministarstva koji imaju direktnu potrebu za aerosnimkama. Testiranja digitalnih kamera inicirale su do sada sljedeće države: Švedska, Španjolska, Austrija, Finska, Njemačka, SAD, Švicarska i Ujedinjeno kraljevstvo (UK).

4.1 Iskustva i standardizacija testova

Najsveobuhvatniji do sada napravljen test za tri glavna dobavljača digitalnih aerokamera radi *EuroSDR network*

Fig. 9. Test bars for radiometric and geometric resolution on test field Sjökulla

Slika 9. Izgled uzoraka za određivanje prostorne i radiometrijske rezolucije na test polju Sjökulla

Current research activities are oriented towards the development of special institutions that will be dealing with radiometric calibration, while geometric calibration will be done "In-site" during shooting or calibration on the job.

5 Conclusion

The term *digital photogrammetry* has been operational more then ten years in practice. But only with the appearance of digital cameras we can completely speak about digital photogrammetry: from the moment of exposition when image is registered with photoelectric effect, until the moment when all three pieces of spatial information are collected.

For leading vendors of photogrammetric equipment (Intergraph, Leica and Vexcel) the near future in photogrammetry lies in completely automated process; from collecting images to final product. Digital camera represents first step to that completely automated process.

Digital technologies are not perfect (like any other). They bring many advantages (see Introduction), but also the need to change the aspect of thinking about image storage and quality control. We don't speak any more about reel of films. Now we speak about media for storing images in digital form. Media themselves are the question of actual technology (DVD, Blue ray, HD DVD and others).

Digital technology brings also new questions that need to be answered:

- ❑ In what radiometric resolution will the images be storied? (Full 12 bits??)
- ❑ In which radiometric resolution will the images be delivered? (8 bits are readable in almost all photogrammetric workstation, but it represents an image with lower quality).

From camera overview we can conclude that the design of digital airborne cameras is more complex than the design of film cameras. Because of high demands on geometry, and more and more on radiometry, we need to pay special attention to calibration.

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Sara Upchurch and Phil Kern, Manager, Corporate Communications, Intergraph Corporation.

References / Literatura

Cramer, M. (2005): Digital Airborne Sensors – Status and future, High Resolution, Earth Imaging for Geospatial Information, ISPRS Hannover Workshop 2005, Germany.

Cramer, M. (2004): A EUROPEAN NETWORK ON DIGITAL CAMERA CALIBRATION, Photogrammetric Engineering & Remote Sensing, December 2004 "Direct georeferencing"

Ciceli,T., Fiedler,T., Gajski,D. (2003): CCD vs. CMOS: Is era of CCD almost over before it really begun in photogrammetry?, The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXIV, Part 6/W11, Commission VI, ISPRS, Zagreb.

Ciceli, T. (2004): Primjena digitalne kamere u terestričkoj fotogrametriji, Magistarski rad, Geodetski fakultet Sveučilišta u Zagrebu, Zagreb.

Ciceli, T. (2007): Osobna komunikacija s predstavnicima Vexcela, Intergrapha i Leice.

Eastman Kodak Company (2001): Charge-Coupled Device (CCD) Image Sensors, Image Sensors Solutions, Rochester, SAD.

Honkavaara, E. Markelin, L. Ilves, R. Savolainen, P. Vilhomaa, J. Ahokas, E. Jaakkola, J. Kaartinen, H. (2005): In-Flight Performance Evaluation of Digital Photogrammetric Sensors, Earth Imaging for Geospatial Information, ISPRS Hannover Workshop 2005, Germany.

Petrie, G. (2003): Airborne digital frame camera, GeoInformatics 7(6), October / November 2003, 18-27.

Petrie, G. (2006): Further Advances in Airborne Digital Imaging - Several New Imagers Introduced at ASPRS, GeoInformatics, Vol. 9, No. 5, 16-23.

Sandau, R., Braunecker, B., Driescher, H., Eckardt, A., Hilbert, S., Hutton, J., Kirchhofer, W., Lithopoulos, E., Reulke, R., Wicki, S. (2000): Design principle of the LH Systems ADS 40 airborne digital sensor, IAPRS, Vol. XXXIII, Amsterdam 2000.

[URL 1] Fairchild Imaging: CCD 595, 9216 x 9216 Pixel Image Area Full Frame CCD Image Sensor http://www.fairchildimaging.com/products/fpa/ccd/area/ccd_595.htm (23.3.2007)

[URL 2] Mathews, B. Zwicker, T. Flight test results from the Ultra High Resolution, Electro-Optical Framing Camera containing a 9216 by 9216 pixel, wafer scale, focal plane array http://www.fairchildimaging.com/main/documents/CCD_595_SPIE_99.pdf (23.3.2007)

[URL 3] Institute fur Planetenforschung: HRSC on Mars Express, HRSC Experiment http://berlinadmin.dlr.de/Missions/express/kamera/kameraeng.shtml (25.3.2007)

[URL 4] Perko R. (2005) Image Quality: Digital Pan sharpening Versus Full Color Film http://vexcel.com/downloads/photogram/ultracam/whitepapers/Perko-Pansharpen-PEARS-Manu.pdf (15.3.2007)

on Digital camera Calibration (Cramer, 2004). Kako je testiranje zamišljeno u nekoliko faza, rezultati će biti dostupni u okviru Druge faze projekta, koja je još uvijek u tijeku.

Standardizirani postupak testiranja digitalnih aerokamera za sada ne postoji, a jedan je od razloga i različit pristup u izvedbi same kamere. Trenutačno u svijetu postoji nekoliko inicijativa za standardizaciju određenih postupaka prilikom uporabe digitalne aerokamere.

U Njemačkoj o tome vodi računa DIN (Njemački institut za standardizaciju). Trenutačno rade na četvrtom dijelu već postojećih *Fotogrametrijskih standarda*. U prva tri dijela opisani su postupci pri uporabi analognih aerokamera za snimanje iz zraka, za skeniranje analognih snimki, te za izradbu ortofota. U četvrtom dijelu bit će napravljeni standardi za digitalnu aerokameru.

Uz to ISO sa svojim povjerenstvom ISO/TC 211 Geografske informacije / Geomatika radi na novim normama za rasterske formate.

4.2 Kalibracija

Kalibracija se može opisati kao postupak definiranja odgovora sustava na poznate, kontrolirane ulaze, odnosno određivanje postavki koje će omogućiti upotrebu digitalnih snimki za potrebe izmjere ili interpretacije. Kalibracija se izvodi posebno za geometriju snimke i posebno za radiometrijske karakteristike.

Građa analognih kamera temelji se na visokokvalitetnom objektivu (npr Zeiss: Pleogon, Lieca: Aviogon i Jena; Lamegon) minimalne distorzije (< 10µm) visoke simetrije, pa se za mnoge primjene može tretirati kao objektiv bez distorzije, te na dobro fiksiranom filmu. Kod takvih kamera elementi unutarnje orijentacije (žarišna duljina, položaj glavne točke i uzorak distorzije objektiva) određeni su u vrlo rigoroznim kalibracijskim uvjetima, te su bili konstantni kroz dugo razdoblje. Snimanje se temelji na centralnoj projekciji.

Kod digitalnih aerokamera situacija je kompleksnija. Zbog ograničenja u veličini senzora, kao što se vidi iz priloženog opisa, nemamo jedan nego više njih. Samim time imamo i više objektiva. Korišteni objektivi u takvim rješenjima često nisu objektivi izrađeni samo za fotogrametrijske namjene, te ni nemaju identične elemente unutarnje kalibracije. Sljedeći razlog za posebno obraćanje pozornosti na kalibraciju kod digitalnih sustava proizlazi iz načina na koji snimka nastaje; spajanjem više snimaka (ili linija u slučaju linijskog skenara) u jednu. Time se gubi centralna projekcija karakteristična za analognu kameru. Uz gore navedeno, i senzor kao novi medij za registraciju ima svoje zakonitosti i pravila u ponašanju koja također utječu na geometriju snimke. Sve navedeno rezultira time da je kalibracija digitalnih kamera veoma važan segment, toliko važan, da sve kamere imaju integrirana rješenja koja obavljaju postupak unutarnje orijentacije prilikom svakog snimanja. Međutim upravo zbog nestalnosti elemenata unutarnje orijentacije, potrebno je napraviti i klasičnu kalibraciju kamera barem jednom godišnje (ako ne i češće).

Trenutačno postoji nekoliko različitih organizacija koje se bave kalibracijom digitalnih aerokamera na globalnoj razini:

1. Povjerenstvo I ISPRS-a
2. CEOS (Committe of Earth Observing Satelites)
3. USGS (US Geological Survey) Digital Camera Characterization initative
4. EuroSDR network on Digital camera Calibration.

Sadašnja istraživanja idu u tom smjeru da se posebne institucije brinu o radiometrijskoj kalibraciji, dok bi se geometrijska kalibracija izvodila prilikom snimanja na mjestu snimanja.

5. Zaključak

Pojam digitalna fotogrametrija već je desetak i više godina uvriježen u praksi. Međutim, tek se s pojavom digitalnih aerokamera može u potpunosti govoriti o digitalnoj aerofotogrametriji: od trenutka ekspozicije, kada djelovanjem fotoelektričnog efekta biva registrirana snimka, pa do trenutka kad u postupku restitucije prikupljamo sve tri prostorne informacije o traženom objektu kartiranja.

Vodeći proizvođači opreme za fotogrametriju (Intergraph, Leica i Vexcel) bližu budućnost fotogrametrije vide u potpuno automatiziranim procesima, od prikupljanja snimaka pa do konačnog produkta. Digitalna kamera je prvi korak prema tom potpuno automatiziranom svijetu fotogrametrije.

Digitalna tehnologija nije savršena (kao ni jedna druga). Sa sobom nosi već nabrojene prednosti, ali i promjenu načina razmišljanja o čuvanju snimaka i kontroli kvalitete. Više ne govorimo o rolama filma već o medijima za čuvanje snimki u digitalnom obliku. Sam je medij stvar trenutačno aktualnih tehnologija (HD DVD, BlueRay).

Digitalna tehnologija nosi i pitanja na koja će tek trebati odgovoriti:

- ❑ U kojoj radiometrijskoj rezoluciji čuvati snimke? (punih 12 bita?!?)
- ❑ U kojoj rezoluciji isporučivati snimke? (8 bita čitljiva je na većini fotogrametrijskih stanica ali predstavlja snimku narušene kvalitete).

Iz pregleda načina izvedbe digitalnih kamera možemo zaključiti da je konstrukcija tih kamera kompleksnija u usporedbi s analognom aerokamerama. Zbog visokih zahtjeva za geometrijom, i sve više za radiometrijom, potrebno je posebnu pozornost posvetiti njihovoj geometrijskoj i radiometrijskoj kalibraciji.

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