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The Z/I Imaging Digital Aerial Camera System

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ABSTRACT

With the availability of a digital camera, it is possible to completely close the digital chain from image recording to plotting. The key decision regarding the camera design in this case is whether a CCD sensor should be used on a line or a matrix basis. In view of the high geometric accuracy requirements in photogrammetry, Z/I-Imaging focused its development on a digital camera based on a matrix sensor. An essential aspect of this decision was not only the aerial camera system, but the entire photogrammetric process to the finished photo or mapping product was also taken into account. The approach chosen will also maintain the usual central perspective for the new digital images.

1. INTRODUCTION

In photogrammetry, the trend is moving away from analog towards digital systems. At present, the camera is the missing link required to completely close the digital chain from image recording to the plotting and generation of photo products. The direct digital image recording procedure promises a totally new dimension in product quality.
Existing film-based aerial survey cameras are not going to be replaced in a single revolutionary step. It will not be possible in the near future to replace all properties of the large film formats combined with the high resolution by a digital camera system.
However, even at this early stage a host of applications already exists for which the full resolution is not required. The lower resolution of digital cameras is more than outweighed in these cases by the considerably higher dynamics in radiometry and the high geometric measuring accuracy. This is made possible by the intrinsic stability of the silicon chip and by the geometry of the individual CCD pixels defined by means of high-precision structuring processes.
A camera must be developed with the objective of implementing today's technologies in a digital camera in the form of a modular design, and to devise the system in such a way that new developments in the field of CCD, computer and mass storage technologies can be made directly available.

2. REQUIREMENTS

The user will only be prepared to accept digital technology if it offers an advantage over existing systems from an economical viewpoint. For this purpose, the entire process chain must be analyzed (Heier,1999), starting from the flight planning and the actual aerial camera system to the finished product in the form of a map or orthophoto.
With respect to aerial photographs, this means that the direct recording of digital data saves a considerable amount of time because the need for film material and regular lab costs is eliminated. In addition, high-resolution panchromatic images and multispectral data can be captured simultaneously during a photo flight.
The overall system must guarantee high operational safety. In Europe in particular, the restricted number of good photo flight days make utmost functional reliability an absolute must. This should go together with ease of operation and a very similar operational philosophy as in existing camera systems.

2.1. Camera system

To achieve utmost photo flight efficiency it is essential to cover a wide terrain area with one single flight strip. Here, present film based aerial cameras have set a standard with 153 mm lenses (6"). With the 230 mm film format used, this results in a cross-track coverage of >70°. The demands on the photo quality are high: in addition to good resolution it is above all the geometric accuracy which is of decisive importance for photogrammetric applications.
The advantage of a direct digital image recording technique is the high radiometric image quality, allowing interpretation of images even in sharp shadowed areas The camera's front end electronic system must provide a resolution range of at least 10 bits. In addition to the actual resolution, the emphasis lies on the dynamics of the entire scene. The processing of specular reflections from a scene, causing so-called blooming due to the spreading of overflowing CCD-cells into neighboring pixels, poses a problem for CCDs. This may destroy the evaluation capability of whole image areas. For this reason, the CCD architecture must be provided with an efficient anti-blooming circle permitting 10x to 100x overexposure. When selecting the pixel size, care should be taken to ensure that the pixel area is proportional to the saturation performance of the chip. In other words, the larger the pixel, the higher the CCD dynamics.
If flights are to be performed in poor light conditions, high-performance lenses with a wide aperture and highly sensitive CCD sensors are required. This can be achieved through the use of low-noise electronics and a CCD sensor with low dark current characteristics.
As in existing cameras, image-motion compensation is the key to sharp aerial images under poor light conditions and at low flying levels. This also guarantees uniform geometric resolutions in the X and Y directions on the ground.
When selecting the color filters, care should be taken that the bands of the spectral channels are not too narrow, so that sufficient energy can reach the detectors. When it comes to the dimensioning of the filters in the visible spectral range, this should be adapted to the sensitivity of the eye curve to generate as realistic a true color impression as possible for interpreting purposes.
The system must be versatile to use; in particular it must allow simultaneous image recording in the panchromatic band, the visible color band and optional the color infrared band, to cover also future applications in the field of remote sensing.

2.2. Mass storage

The mass storage capacity must be such that it can accommodate at least the full image data quantity which is produced in one day. Here, the restricted space conditions in typical photo planes must be taken into account in the overall size and weight of the unit.
An example is given to illustrate this:
With each recorded image, a digital camera with a resolution of 10 000 x 10 000 pixels in the panchromatic channel, and 5 000 x 5 000 pixels in the RGB channels, produces 175 MPixels, which generate 350 Mbytes of data with a storage format of 2 bytes. Based on an image recording quantity of 1000 frames, this corresponds to about 2 rolls of conventional film and a required storage capacity of 350 GByte, if not compressed.
When reading out data from removable data carriers, the times must be kept short, because large data quantities need to be transferred and processed in an initial cycle. Early flight results are of the essence - preferably already in the plane via a Quick Look function - in order to provide instant quality assessment. This includes, for example, the assessment of the image quality as regards color, contrast and cloud cover of the recorded scenes.
For the actual applications, the usual flying heights and variable terrain heights should be observed in the photo flights.

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2.3. Postprocessing

This process describes the processing of raw data. It is also where the geometric and radiometric correction of image data, the optional computation of navigation data from the photo flight and the compilation of the flight report are performed.
Important requirements are fast processing of raw image data into deliverable image material and far-reaching automation of the relevant processes.

2.4. Photogrammetric software

It should be possible to process the digital images using existing softcopy systems. It can be assumed that existing photogrammetric companies will perform the parallel processing of direct digital data and scanned film data on existing digital photogrammetric in the near and medium-term future. Entirely different photogrammetric software for film scanned and direct digital camera data must therefore be considered uneconomical for the user.
An archiving system and an image data management system are required as final step, permitting data and resulting end products to be secured.

3. SYSTEM DESCRIPTION

When selecting a digital camera system, it is, as previously described, not only the camera onboard the plane which needs to be taken into consideration, but the entire process must be analyzed including the finished product and data archiving.

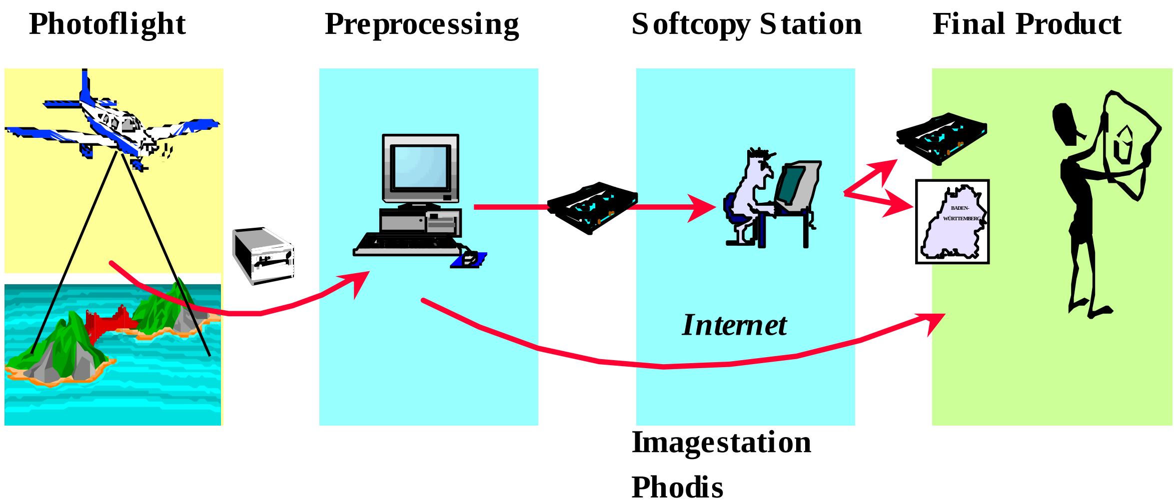

Figure 1: Illustration of the complete system.

3.1. Flight system

The flight system includes the actual digital camera for recording image data. The optional infrastructure onboard the plane will comprise the usual equipment such as navigation systems, flight management system, GPS- INS, a stabilized platform, etc. The film cassette or film magazine are now replaced by the mass storage unit.

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3.2. Camera head

The centerpiece of the system is the camera head and the CCD sensor as the core element.
Z/I-Imaging has decided to develop a new digital camera generation on the basis of CCD matrix sensors.
The driving factor for this decision was an intensive evaluation of the competing approaches on the basis of a line sensor and a matrix solution. The fundamental properties were already discussed during the Photogrammetric Week in 1997 (Hinz, 1997).

Clear benefits of the matrix camera:

- defined, rigid geometry of the recorded image
- Forward Motion Compensation (FMC) to reduce image blur
- Quadratic pixel footprints
- usual, central perspective image recording geometry
- interfacing to existing softcopy systems software

For technological and economical reasons, it is not possible to choose the ideal solution which would be one individual, large-area CCD chip in the size of a silicon pizza, similar to existing film formats.

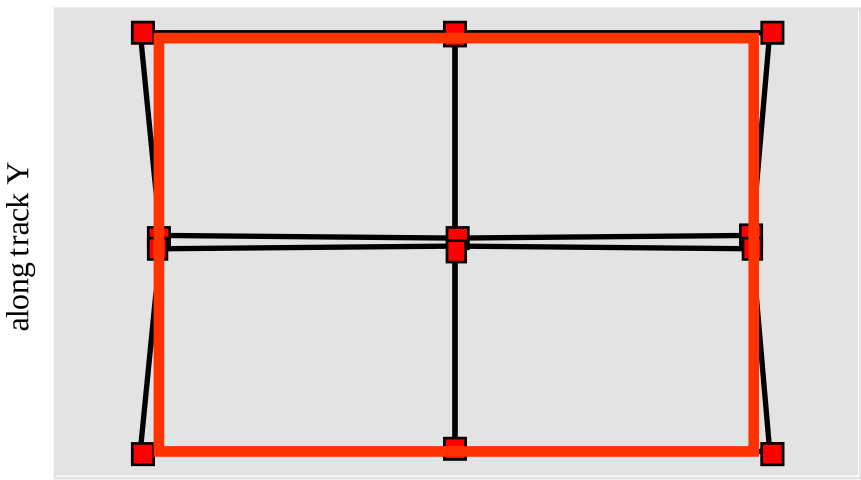

Figure 2: Ground coverage of 4 camerahead system.

However, for the image recording procedure it is important to have as wide a ground coverage with one shot as possible. This is made possible by parallel operation of several compact camera heads directed at the scene under slightly displaced field angles. Figure 2 shows a ground print taken with four such camera heads. This modular approach permits simple scalability of the overall system.
The principle of parallel image recording has been established and successfully used for more than 30 years in reconnaissance cameras such as KS-153, and drone systems such as KRb 8/24.
Each CCD chip is assigned its own lens. Today, CCD chips are available in pixel sizes from the consumer market of 2 million pixels. In the field of professional photography, 6 million pixels (2K x 3K) are available as a result of reliable high-volume production.

Different manufacturers (Kodak, Philips, Lockheed Martin) offer chips between 4K x 4K, 7K x 8K and 9K x 9K, with pixel sizes of 9 µm to 12 µm which are produced in small series.
The main idea behind the approach of the DMC digital camera from Z/I-Imaging is the system's modular design with rapid adaptability of new developments in the field of CCD, microcomputer and mass storage technology. Depending on the application, several camera heads can be combined. This provides lateral resolutions from 4K to 14K using components available today.

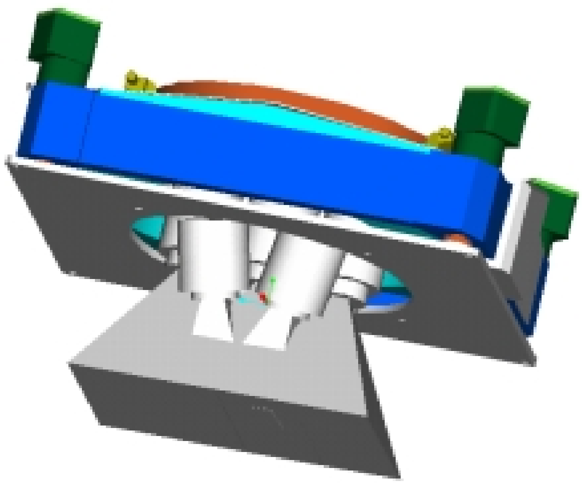

Figure 3: Illustration of optical arrangement of 7 head camera.

Fig. 3 gives a sketch of an example with 7 camera heads.
The system consists of a camera configuration integrated in the stabilized T-AS platform. The panchromatic channel has been implemented with 4 cameras. The spectral channels with a resolution reduced by half in the linear dimension, have one camera each for red, green and blue, covering an identical ground area. The pyramid cones shown in the illustration represent the different field angles of the lenses. The system can be extended by additional spectral channels (i.e. Infrared) for remote sensing applications.

3.2.1. Forward Motion Compensation (FMC)

FMC is one of the most important milestones in aerial photography and was introduced by Carl Zeiss Jena in 1982 (G.Voss, 1983).
A full frame matrix CCD sensor implements FMC on a completely electronic basis. The following illustration explains the principle: During the read out process, the charge contents of the CCD pixels are transported line by line to the readout registers and then read out. If this shifting process is performed synchronously to the pixel motion on the ground during exposure, it is possible to compensate for the flight motion by means of an electronic procedure.

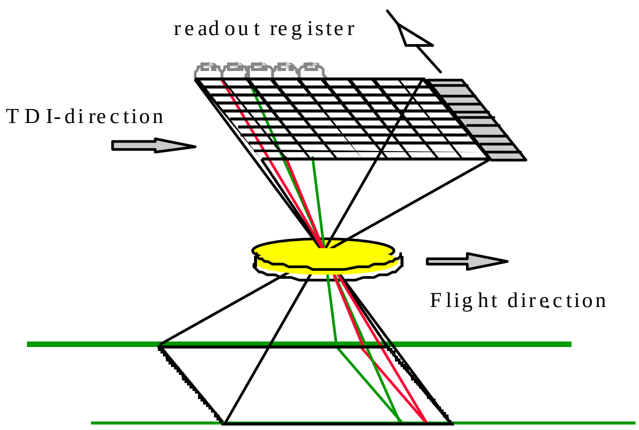

Figure 4: Principle of time delayed integration.

This technique has already been successfully used by IGN C. Thom (1997) for photogrammetric purposes, and was demonstrated for Recce cameras by Recon Optical and Lockhead Martin (B. Mathews, 1998) The following illustrations Fig. 5 shows the results obtained with a moving resolution target on a simulator, achieved with a test configuration of a digital CCD matrix camera in our laboratory.

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Moving target, compensated   Moving target, uncompensated

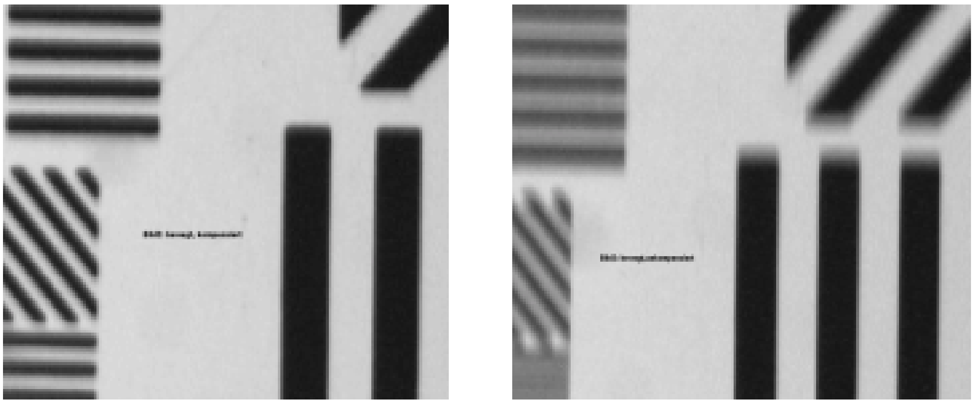

Figure 5: Resolution target with / without motion compensation.

3.3. Mass storage

This should preferably be a removable data carrier like an RAID system or tape cassettes. The definition and selection of these components need special care. Commercially available components of the computer market may be used, but these need to be subjected to a special hardening procedure for onboard use of an airplane. Special qualification must be taken to allow for environmental conditions such as air pressure, temperature and vibrations.

3.4. Ground Station and Preprocessing

Digital data is transported on an appropriate data carrier or a removable disk to the ground station. The latter may be a simple office, e.g. in the hangar, where the data is edited and processed. This editing comprises, for example, the copying of data, radiometric and geometric corrections and quality control. On a carrier medium - in the future maybe per Internet if powerful transmission routes are available - the data are then forwarded to an office the for final softcopy and production process.

3.5. Softcopy office

This is where data - depending on the degree of initial processing - is further processed into the intended end product. Ideally, the data should be supplied in the same form as a scanned central-perspective aerial photograph.
All necessary preprocessing steps should be virtually automatic. It is essential to make use of existing hardware and softcopy installations, to keep the investment costs for further equipment and softcopy programs low. This applies in particular to the additional costs for training of operators.

4. CONCLUSION

The digital camera introduced by Z/I-Imaging is based on a matrix CCD-Sensor. This approach offers the best geometric accuracy for photogrammetric applications, without any reliance on inertial and GPS data. The high intrinsic accuracy is determined by the two dimensional CCD-matrix on top of a silicon wafer. It more or less offers several million well defined fiducials (=number of CCD-pixels) in the image plane of the aerial photo. The modular approach allows the combination of several compact camera heads offering cross track coverage in the same range as standard wide angle aerial cameras. High flexibility allows adaptation of resolution and spectral channels to the customers needs. The resulting digital image has the usual central perspective geometry, thus maintaining interfacing and compatibility to existing soft copy solutions. For the near future, the coexistence of large format film based aerial cameras and the new digital generation of cameras will be the observed. The introduction of the new quality and applications of digital camera systems will be an evolutionary process with demanding objectives.

5. REFERENCES

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