DIGITAL MODULAR CAMERA:

SYSTEM CONCEPT AND DATA PROCESSING WORKFLOW

Alexander Hinz, Christoph Dörstel, Helmut Heier,
Z/I Imaging GmbH.
73442 Oberkochen, Germany
{Hinz, Doerstel, Heier}@ziimaging.de

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ABSTRACT

At the moment, fundamental changes in sensors, platforms and applications are taking place. The paper describes present development activities and future application aspects of data processing and automation in the workflow of the Digital Modular Camera DMC from Z/I Imaging.

For many decades, Aerial Cameras developed and manufactured by Carl Zeiss Photogrammetry Division have been used successfully all over the world as high performance systems for aerial photography. These activities are now completely taken over by Z/I IMAGING, an Intergraph - Carl Zeiss joint venture.

At present, two different approaches of digital camera systems, one based on linear sensors and the other based on matrix sensors, are under development. The key issue of the whole photogrammetric system process is the geometric image accuracy, which is mostly defined by the camera sensor itself. In order to fulfill the high requirements of mapping applications, ZI Imaging has decided to base the new DMC on a CCD-matrix sensor. High ground coverage of this new approach is achieved by a combination of several camera modules, where each CCD sensor is mounted to its own lens. First flight tests with a demonstrator have already shown high resolution and accuracy in the centimeter range at low flying altitudes, due to the electronic FMC function of the DMC.

This paper also gives a complete overview of the needed data processing steps and the integration of DMC imagery into existing photogrammetric workstations. The paper discusses in detail the fully automatic data post-processing steps, to apply sensor normalization for each CCD array, the functional approach of setting up panchromatic image mosaics and finally the generation procedure for color composites. Additional focus is drawn to several image products optionally deliverable directly from the post-processing procedure.

1 INTRODUCTION

The digital camera system DMC uses a modular design to achieve high geometrical resolution and to enable customization for optimum system performance. The DMC comprises a variable number of synchronously operating CCD-matrix based cameras that can be mounted together in different configurations, depending on the application. This multi-camera approach allows the combination of high panchromatic resolution with multi-spectral capability.

The idea to enlarge the field of view by combining several lens systems is well known since the early days of aerial photography. Several Aerial Cameras with 2, 4, 7 and even 9 lenses were built [Szangolies, 1986], [Talley, 1938]. In 1926, Aschenbrenner conceived a 9-lens camera system of 53.5 mm focal length covering a field angle of 140°. This camera had already a negative format of 250 x 250 mm. Complicated special rectifiers and plotting instruments were developed to restore the image geometry. Handling of this image evaluation instruments was troublesome and the use of multi-lens cameras came to an end during the late 1940's after camera manufactures like Zeiss had developed new single-lens cameras with larger negative format. Nowadays, the image restoration of such a multi-lens camera can be done completely by photogrammetric software opening up new possibilities.

2 AIRBORNE CAMERA SYSTEM

2.1 System Description

The following figure shows a typical installation of the DMC system in an aircraft, which is almost identical to existing film camera installations.

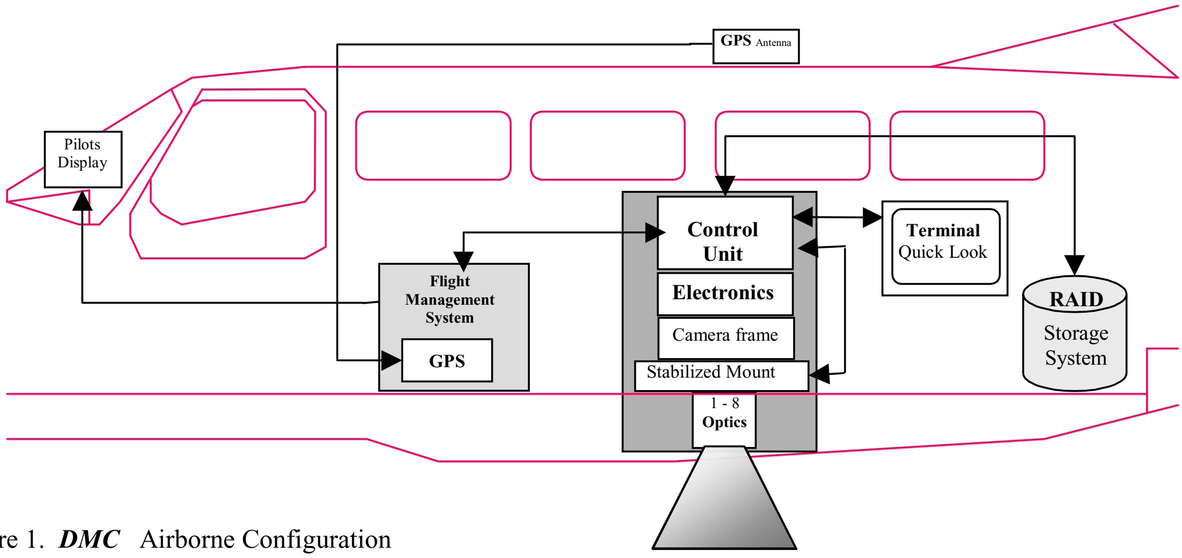


Figure 1. ***DMC*** Airborne Configuration

The flight management system with optional pilot's display and an optional inertial measurement system like Aerocontrol can operate either the DMC or an already existing film camera. The DMC camera head has similar dimensions as the RMK-TOP camera and fits in the existing gyro stabilized platform T-AS. The camera itself consists of an optics frame, which slips into the platform bore. The frame can take up to 8 camera modules: 4 high resolution panchromatic CCD lens modules and 4 multispectral channels with reduced resolution. The camera modules are mounted inside the optics frame. Special efforts have been invested on rigid mounting technology for the individual camera heads in order to ensure precise alignment of the optical axes to each other. The front end electronics of the CCD's are directly integrated into the single camera modules.

On top of the optics frame above the stabilized gyro-mount is the camera electronics box. This unit houses the complete camera head electronics, which controls the camera modules, collects the image data and communicates with the control unit. The control unit configures the complete system, communicates with the external systems, monitors the data flow and stores data onto the RAID. The power electronics for the shutter units are also integrated inside the camera unit. The system can be operated by an external terminal, a Quicklook display gives overview images for system and quality control.

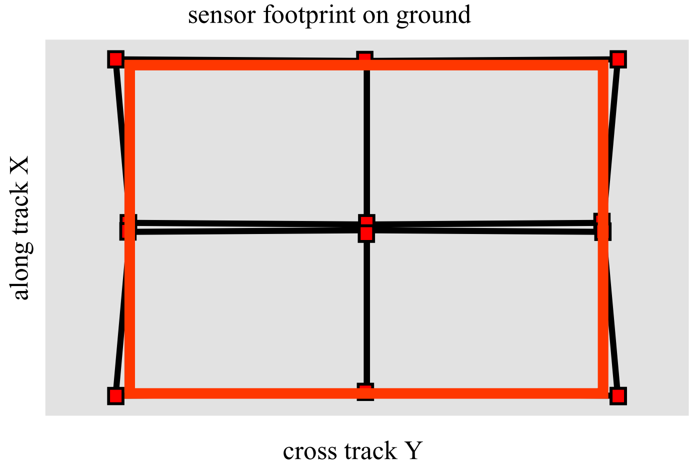
Finally, the image data are stored on a RAID hard disk system with removable storage units. The RAID system is placed in a separate housing and connected to the electronics magazine via a high speed FDDI interface. Full modularity allows easy adaptation of standard storage devices to the system. Depending on the application and the requirements, an appropriate number of storage units can be plugged into the system.

The whole system can be operated by the terminal and/or a flight management system, an optional Inertial Measurement Unit (IMU) can be integrated into the system, opening up the possibility to work without ground control, or with a reduced set of ground control points.

2.2 Optical Concept

The centerpiece of the system is the camera head and the CCD matrix sensor as the key element. For technological and economical reasons, it is not possible to choose the ideal solution which would be one individual, large-area very expensive CCD chip the size of a “silicon pizza”, similar to existing film formats.

However, for the image recording procedure it is important to have a ground coverage with one shot as wide as possible. This is provided by parallel operation of several compact camera heads, where each CCD has its own lens. The modules are directed to the scene at 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 camera systems such as KRb 8/24.

The high resolution version of the DMC is equipped with four 7k x 4k large area chips and f/4 high performance lenses with a focal length of 120 mm in the panchromatic channel. Special care has been taken to assure homogenous and flat response of the MTF (Modulation Transfer Function) over the entire image field of the lenses.

Figure 2. Ground coverage of 4 head camera system

Figure 3 shows the arrangement of the 4 panchromatic channels in the optics frame. The resulting resolution of the system on ground is > 12,000 pixels across track and approx. 8,000 pixels along track. The resulting cross track coverage angle for the system is 74°. The mechanical size of the optics frame is compatible with the RMK lens cone dimensions to fit into the existing T-AS gyro stabilized mount.

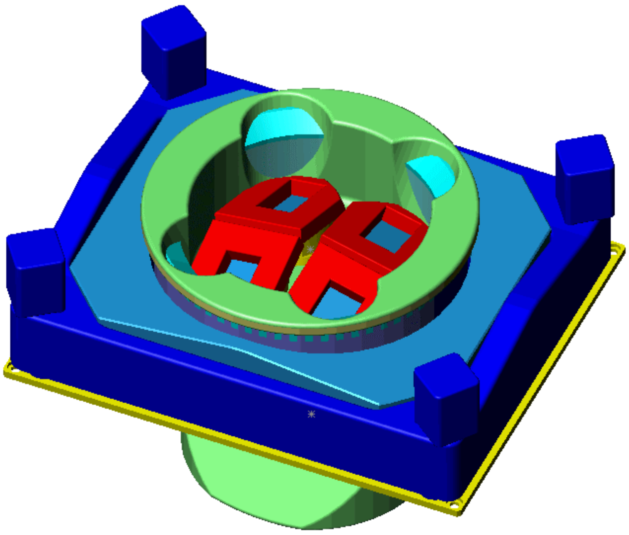


Figure 3. Panchromatic channels in gyro stabilized mount

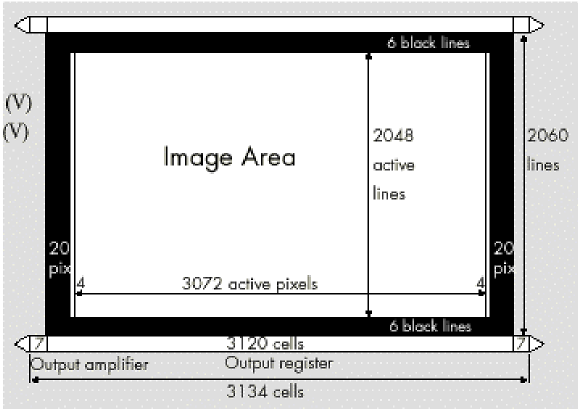
The color channels are mounted on the outer rim of the optics frame, up to 4 channels can be added to the system. This allows the collection of images for instance in the Red, Green, Blue and a separate Infrared channel for taking simultaneous true and false color images at the same time.

In order to achieve high quality color separation, each color channel features a separate lens, a CCD-chip and a high performance color filter, based on non-organic material. The color channels have reduced ground resolution compared to the panchromatic channel and the lenses are looking down in central perspective view. A high performance wide angle lens with high opening f/4 and f=25 mm is combined with a 3k x 2k CCD chip. The resulting overlap of the spectral channels (given in grey bold rectangle) and the panchromatic channel (black thinner lines) is illustrated in figure 2.

2.3 CCD - Sensors

The CCDs are full frame sensors with high optical fill factor and sensitivity and are manufactured by the Philips company in Eindhoven. Pixel size is 12 µm x 12 µm, offering a high linear dynamic range > 12 bit. The architecture of the CCDs offers 4 readout registers on every corner of the chip (figure 4). This provides high readout rates, which is important for a good S/N (signal to noise) ratio of the signals and a repetition rate of the system achieving one image every 2 seconds. The front end electronics, generating the CCD control, timing signals and the digital signal read out circuits are placed directly behind the CCD housing in order to ensure low noise performance of the system. Digitizing of the CCD signals is done with 12 bit resolution.

An electromechanical shutter system is used to control the light exposure of the CCDs. Every optical module is equipped with such a shutter, placed in the center of the lens. The advantage of this solution is an almost distortion free image, since all image points are exposed through the same optical path at the same time. A slit shutter, as used in almost every standard reflex camera, causes a geometric distortion inside the image field, since the aircraft is moving during the exposure time.



One focus of the shutter development was to achieve precise synchronization of all lenses to ensure exposure of all images at exactly the same time interval in order to exclude geometric errors.

The CCD electronics can be operated in time delayed integration (TDI) mode during the exposure of an image. This allows fully electronic forward motion compensation of the digital image (Hinz PhoWo '99). In this way, compensation of image blur at low altitude and high resolution applications is ensured as is standard in film cameras since 1982.

Figure 4.
Layout Philips FTF 3020 CCD sensor

2.4 Test Results

A test flight with a single camera module demonstrator system was made in Jan. 2000 together with Terra Bildmeßflug, Elchingen. The camera was installed on board of a Cessna twin engine aircraft. Test flights at different altitudes have been carried out at a flying speed of 70 m/sec. The following image shows the result of a test flight at 300m flying height above ground over the Carl Zeiss plant in Oberkochen. The total symmetrically resolved Siemens Star (diameter 6m) shows the perfect compensation of the forward motion blur which was 7 pixels under the test conditions. Ground pixel size was 7cm, defined by the pixel size of 12µm and a 50mm lens.

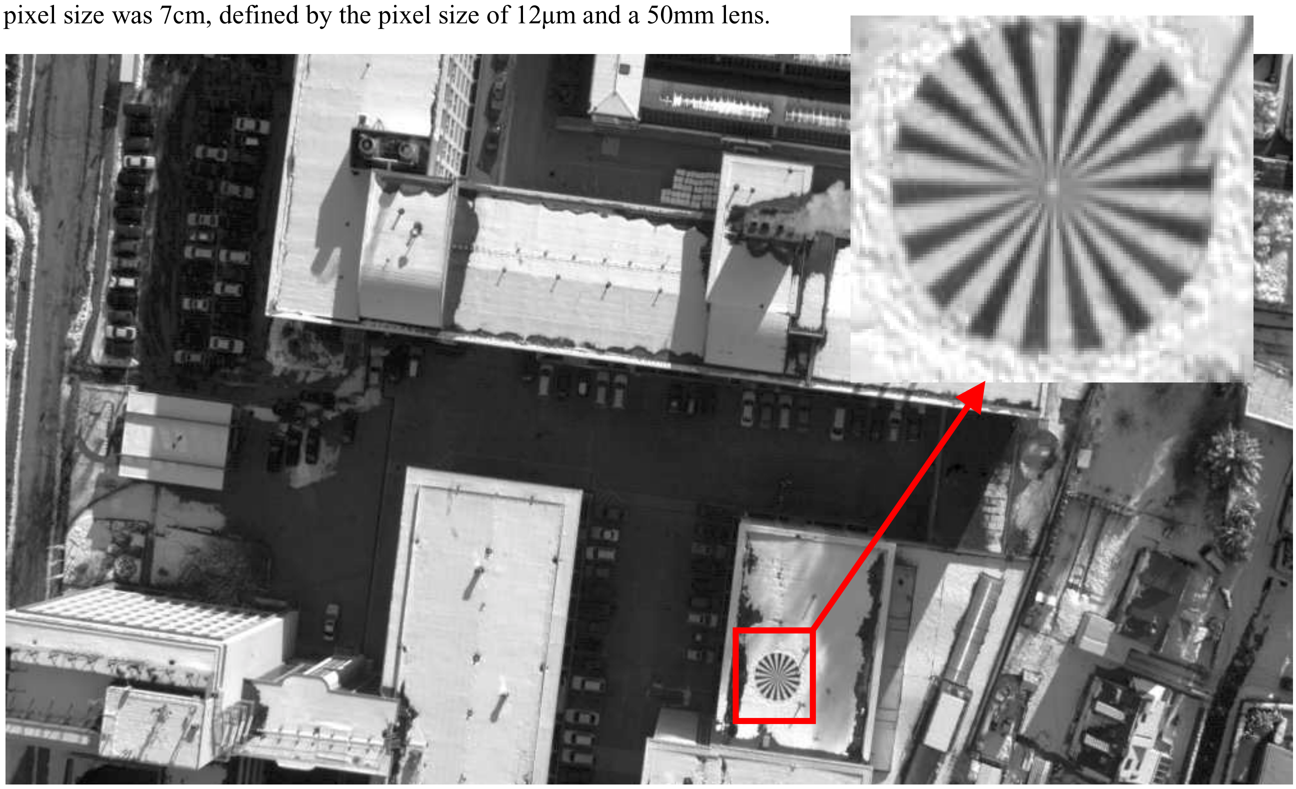


Figure 5. Test Flight over Carl Zeiss Plant Oberkochen

3 DMC SOFTWARE

This chapter describes the entire workflow for processing DMC image data. A presentation of the individual elements is given: from the DMC camera controls in the plane, to the ones used for data post-processing and transferring images and additional information to an acquisition system. Special mention is made of the interface to the ImageStation and the evaluation packages of other manufacturers. The different image data levels are briefly explained. Z/I Imaging is a provider of complete end-to-end digital systems and therefore presents the DMC camera system as one component of a highly integrated system used from mission planning to the creation of end products such as orthophoto maps, for example, or data capture for GIS systems.

3.1 Workflow

Different flight management systems (FMS) are successfully used for the preparation of photo flights. In this field, Z/I Imaging is working together with IGI, Hilchenbach, using their CCNS4 product. In the hangar, the prepared flight management data and, optionally, the camera calibration data are transferred to the flight system. The complete workflow is illustrated in Table 1.

Processing site	Processing steps	Detail
Office	Pre-Processing	Mission planning
Airplane	Photo flight	Navigation and flight management system Camera control software Quickview (In Flight Quality Check) Data storage
Hangar / Office	Post-Processing	Exchange of data storage , RAID Checking option (Quickview / flight report) Post-processing • Radiometric correction • Geometric correction • Mosaicing (generate virtual images) • Color image • Color composite Data archiving and distribution, e.g. TerraShare / E-Geo
Office	Data Acquisition	Data evaluation, e.g. ImageStation

Table 1 Workflow

3.2 Photo flight

During the photo flight, a minimum of two software systems (see Fig. 1) are in operation. These are the flight management system (FMS) and the camera control software. With the help of the flight management system, additional sensors such as GPS/INS or radar / laser sensors can be operated. Additional components can also be installed, for example a navigation telescope.

The camera control software is responsible for displaying such system statuses as flight parameters, e.g. speed above ground (v/h – value), or camera parameters, e.g. available disk capacity or "active sensors". In addition, the control software allows to adapt camera parameters, such as exposure time or shutter, interactively. The camera control software communicates with the FMS, the camera unit and the Quickview.

The Quickview provides the navigator with an early quality control tool (In Flight Quality Check) and offers the necessary basic functions for visualization and assessment of the captured image data. Special, predefined masks facilitate the systematic visualization of individual images of the strip. It is also possible, through direct access to specific image data, to assess the geometric and radiometric quality of the images already in flight. Questions such as possible detail resolution, shading by clouds or radiometric resolution in brown coal open mining, for example, can be checked during the flight and corrected, if necessary.

3.3 Post-processing

After landing, the recorded data are supplied to the post-processing software. For this purpose, the RAID system used in the plane is exchanged for one located in the hangar. This eliminates lengthy data transfer times.

The objective of post-processing is to prepare the original images for evaluation by any existing Digital Photogrammetric Work Station (DPWS). In this work process, the captured image data are normalized, verified, rectified, color coded, formatted and made available for post-processing. After each of these individual steps, data can be transferred to other DPWSs. Additional information relating to the images and the photo flight are provided separately. The possible intermediate products are shown in Table 2.

Product level	Name	Description
Level 1	Normalized original image	Radiometrically (gain/offset) corrected image including elimination of defect pixels.
Level 1a	Virtual image	Individual images are converted distortion-free into a virtual image with central perspective (Mosaicing)
Level 1b	Color composite or color image	Color image = R + G + B Color composite = panchromatic image + color image
Level 2	Georeferenced image	Data generated from level 1a or 1b by GPS/INS measurements

Table 2 Product level

Due to the presently long time required for post-processing of image data, the development of algorithms and work processes is focused strongly on parallel processing and automated batch processing. Here, the user can predefine the project/partial project to be processed, or make a specific selection of strips or images. In addition, the target parameters such as product level, data format, compression factor, image pyramids and auxiliary information are precisely defined.

The image output format can be selected by the user. The standard format for image data to be transferred to other systems is TIFF – JPEG.

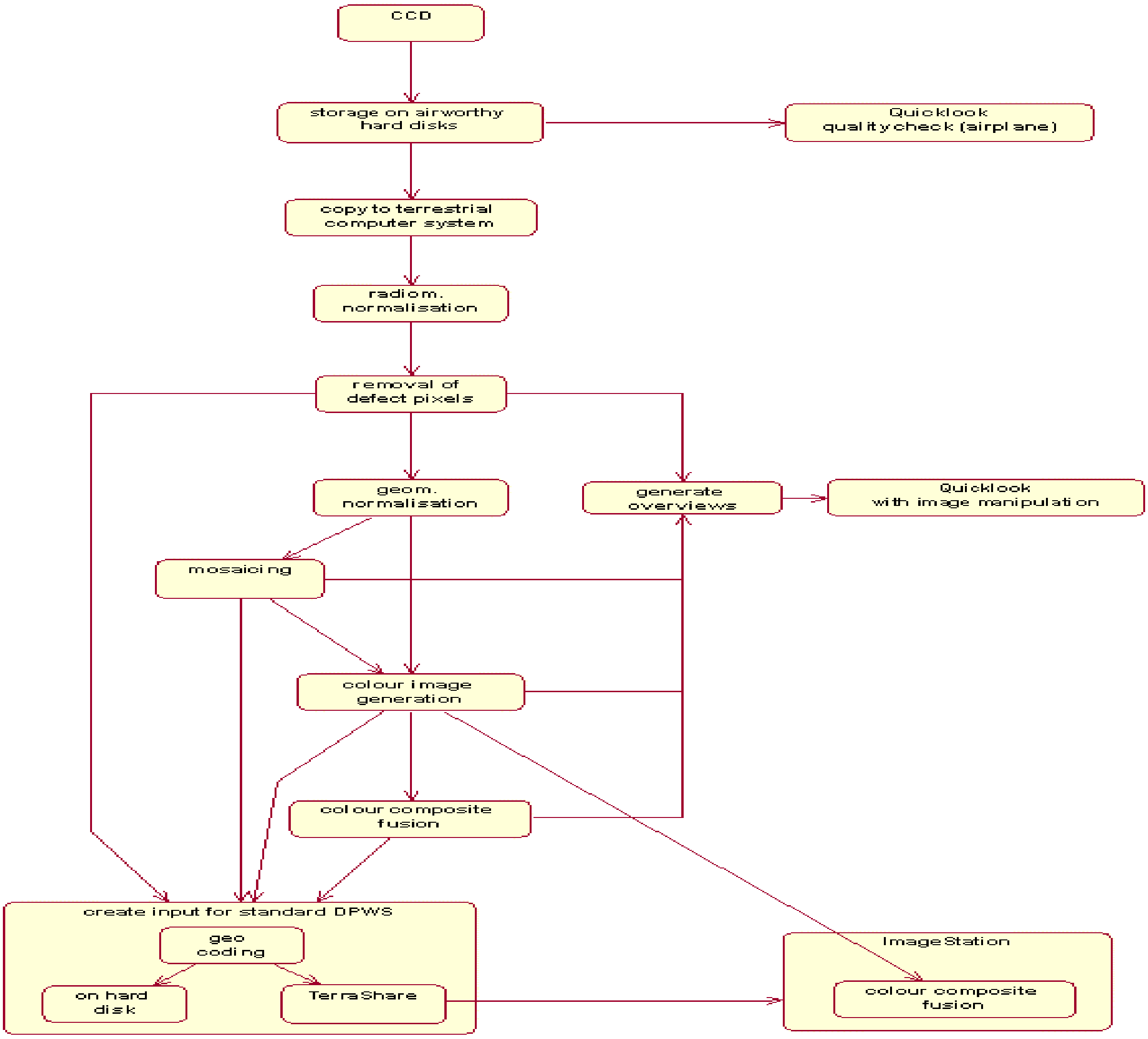


Figure 6 Post-processing Workflow

The workflow of the post-processing software (see also Fig. 6) is explained in detail in the following. The first step – the generation of Level 1 images – is performed on the basis of camera calibration data. This includes the elimination of defect pixels and normalization. In the elimination of defect pixels, which could be individual pixels of poor electronic quality or, if applicable, missing individual pixels are corrected. In the radiometric correction, bright image and dark image corrections are applied to each pixel (Diener, et al, 2000). Data acceptance can then take place on site. Here, too, the Quickview helps to systematically screen the entire data.

Next, the image data are geometrically converted and combined by the mosaicing module. Before the virtual image is generated, the lens distortion is geometrically corrected based on the camera calibration. Here, the calibrated 3D location of each individual image level is taken into account and verified by cyclic control measurements. The image created in this way has a new, virtual camera constant and can be considered an ideal photogrammetric image.

Parallel to image conversion, the individual multispectral channels are now combined. For this purpose (Diener et al, 2000), the RGB channels are first combined by means of color matching. Also in this process an optimum result is obtained due to existing camera calibration and cyclic control measurements. The color image thus produced is then, if necessary, combined together with the panchromatic image to the so-called color composite.

As a result of these processing steps, the image data can be transferred to a data management system, e.g. TerraShare, where it can be archived or be distributed directly via E-Geo to the destination defined by the operator or as requested by the customer. As a preparational measure, each image can be georeferenced on the basis of the preprocessed GPS/INS data.

3.4 Data Aquisition

The integration of DMC sensor data into the Image Station can be based on the images of Level 1a, 1b or 2. In this case, the DPWS can be operated in the mode for aerial frame cameras. If the ImageStation 2000 is used as a DPWS, it is possible to use both the color image and the mosaic, if necessary. That means, both images can be stored in different files, without having the need to pre-compute the color composite: The required disk storage capacity can therefore be reduced about 2.6 times. (see Table 3).

	10 - 16 bit image	8 bit image
Color image	36 MB	18 MB
Virtual image	224 MB	112 MB
Sum (color image + virtual image)	260 MB	130 MB
Color composite (virtual image with 3 color channel)	672 MB	336 MB

Table 3. Disk storage capacity for uncompressed data stored as a color composite or stored in separate files for color and panchromatic information.

In Table 3, the storage capacity required for a single image with a radiometric resolution of 16 to 10 bit and 8 bit is calculated. In view of the current camera specification, the approach is based on a 7Kx4K chip for the 4 panchromatic channels and one 3Kx2K chip for each of the 3 multispectral channels. The color composite created online in the ImageStation can, if necessary, be generated on the basis of the ImagePipe™. The online generation of a color composite is performed by more or less the same procedures as in stereoplotting or orthophoto generation.

4 PERFORMANCE COMPARISON :

At this moment, airborne digital cameras based on different technical concepts are under development. For a real and objective performance comparison between these developments one has to look into the application related cost situation. Thus, a performance comparison only on the basis of counting picture elements would be a mistake. As regards ground resolution, accuracy, Pixel footprint, light conditions and system compatibility, the DMC offers the best system performance with the technology available today.

1. Resolution

The DMC offers an outstanding ground resolution even for large image scales due to the fact that FMC is implemented. A ground resolution of less then 2 inches has already been proven in a test flight performed in January 2000.

2. Accuracy

The DMC accuracy is defined by the solid state surface of the silicon matrix sensor itself, together with rigid interior orientation of the high precision lenses. Differential GPS measurements and INS results can optionally be used.

3. Pixel footprint:

Due to the framing concept, the DMC delivers quadratic pixel footprints. Influences from airspeed or sudden aircraft movements are eliminated because the image geometry is frozen with one exposure shot.

4. Light conditions - number of days with acceptable conditions

In view of the fact that FMC is an inherent feature of Z/I Imaging's digital camera, high resolution imagery can be taken also under weak light conditions. When using a camera without FMC capabilities, it is not possible to reduce the air speed below certain limits.

5. System Compatibility

The DMC is based on the central perspective image which has been established in photogrammetry for nearly 100 years. All existing exploitation systems can handle these data.

6. Reliability

The image taken with a frame sensor can be used even if the GPS results are not of the expected accuracy. With a line sensor, however, if the GPS results are not satisfactory or missing for any reason, the flight needs to be performed again, because the direct sensor orientation is interrupted.

5 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 having to rely on inertial and GPS data. The high intrinsic accuracy is determined by the two dimensional CCD matrixes on top of a silicon wafer. 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 customer’s needs. The resulting digital image has the usual central perspective geometry, thus maintaining interfacing and compatibility to existing soft copy solutions. Recognizing that today's digital camera systems cannot replace existing film based camera systems, DMC was designed to fit easily into the current film based workflow to combine the best of both technologies in the most economical way. The DMC can be used in addition to RMK-TOP components and it will help to tailor this investment to the digital future.

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