IMAGE TIME SERIES FOR NEAR REAL TIME AIRBORNE MONITORING OF DISASTER SITUATIONS AND TRAFFIC APPLICATIONS

P. Reinartz, F. Kurz, D. Rosenbaum, J. Leitloff, G. Palubinskas

German Aerospace Center (DLR), Remote Sensing Technology Institute, PO Box 1116, D-82230 Weßling, Germany,
peter.reinartz@dlr.de

Commission I, WG I/4

KEY WORDS: Aerial cameras, image series, near real time processing, traffic parameter extraction, direct georeferencing, emergency response, middleware

ABSTRACT

Near real time monitoring of natural disasters, mass events, and large traffic disasters with airborne optical sensors is a focus of research and development at the German Aerospace Center (DLR). For this purpose, a new airborne camera system was developed named 3K camera system (3K = "3Kopf-Kamera"). Image data are processed onboard on five onboard processing units using data from a real time GPS/IMU system. Processed data are sent to ground via two types of data links, a commercial microwave operating in the S-band. This system is called ARGOS. The data received by the ground antenna are further processed and distributed directly to the ground forces and to different institutions like the ZKI (Center for Satellite Based Crisis Information) and a traffic portal of DLR. The time span between acquisition and reception at the end user is about 5 minutes. Main focus in the current development is the traffic processor, which extracts traffic information like traffic density and vehicle velocity from 3K image sequences. The information from a road database is used for the road and vehicle detection in the georeferenced images. Another application is the thematic mapping of natural disasters like floods, land slides, and damages after earth quakes. The requirements of civil security and rescue forces for a near real time airborne monitoring system were integrated in the first prototype system, which should be ready in the middle of 2009. National cooperation partners are the Federal Office of Civil Protection and Disaster Assistance (BBK) and the Federal Agency for Technical Relief (THW) supplemented by different regional civil security institutions in the two demonstration regions Cologne and Munich. The future plan is to operate a quickly reacting mobile ground station and an airplane on standby for monitoring of natural disasters and mass events. In this paper the relevant parts of the overall system and selected system processes are addressed and described. The experiences made in the flight campaigns of the last years are summarized with focus on the image processing part, e.g. reached accuracies of georeferencing and the traffic processors.

1. AIRBORNE RAPID MAPPING

Rapid mapping for natural disasters was long time the domain of satellite images which were processed and distributed by institutions like the ZKI (Center for Satellite Based Crisis Information) at the DLR. Airborne rapid mapping can fill a gap as satellites are fixed to overpass times and are thus not available at any time. Besides, airplanes can be directed flexibly with a high spatial and temporal resolution.

Ongoing projects like VABENE (DLR), and SAFER (E.U.) try to fill this gap and enforce the application of airborne rapid mapping in case of natural disasters and mass events. In the projects VABENE and SAFER, airborne rapid mapping systems will be developed and validated together with the national rescue forces and security related forces (BOS). In the VABENE project, a DLR traffic portal will be developed to equip the forces with powerful tools like traffic prognosis and traffic routing supported by the data from the ARGOS rapid mapping system. The development of these systems was in close contact with the national rescue and security related forces. The first prototype of the rapid airborne mapping system should be ready in the middle of 2009.

In this paper, an overview of all relevant parts of the airborne rapid mapping system is given and selected system processes are addressed and described in more detail. The experiences made in the flight campaigns of the last years are summarized with focus on the image processing part, e.g. reached accuracies of georeferencing and status of the traffic processors.

2. SYSTEM HARDWARE

2.1 DLR 3K camera system

One important part of the overall system is the DLR 3K camera system, which consists of three non-metric off-the-shelf cameras (Canon EOS 1Ds Mark II, 16 MPixel each). The cameras are aligned in an array with one camera looking in nadir direction and two in oblique direction, which leads to an increased FOV of max 110°/31° in across track/flight direction. The pixel size and swath width are depending on the flight altitude and

range between 15 cm to 50 cm and 2.5 km to 8 km respectively. This camera system can be operated in different mapping or traffic acquisition modes and thus a high resolution, colour and wide-area monitoring task even at low flight altitudes, e.g. below the clouds, is feasible. Within two minutes an area of approximately 10 km x 8 km can be monitored. The frame sensor system is coupled with a real time GPS/IMU navigation system, which enables the direct georeferencing. The ability to acquire image sequences with up to 3Hz broadens the spectrum of possible applications in particular to traffic monitoring.
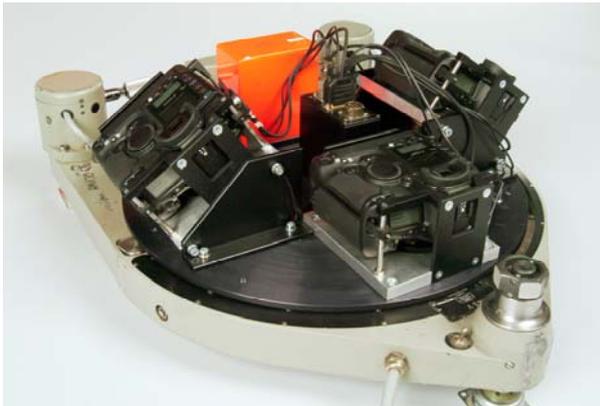

Fig 1. DLR 3K-camera system consisting of three Canon EOS 1Ds Mark II, integrated in a ZEISS aerial camera mount

2.2 Airborne processing units

For real time processing of 3K-camera images a distributed airborne image processing system is currently developed by DLR (see Figure 5) consisting of five PCs onboard. Each camera is connected via firewire to a PC which is responsible for image acquisition, for the orthorectication of images, and for the street segmentation as part of the traffic processor. Data are collected in at the fourth PC, which is responsible for vehicle detection and vehicle tracking. The fifth PC collects all data and sends them down via an S-Band microwave link.

2.3 Microwave data downlink

The processed data are transmitted to a ground station using a commercial autotracking microwave downlink in the S-band with a data rate of approx. 30Mbit/s and a range of 100km. Manufacturer of both antennas is JDA. The technical data of the antenna system are provided in Table 1. Images of the airplane antenna and the ground antenna are in Fig 2 and Fig 3.

Different types of data are sent to the ground station via UDP packages, i.e. there is no feedback that the data are really received by the ground station. Thus, different types of errors can occur: from single bit errors (error rate is appr. $1:10^9$) up to total loss of connection. As the minimum error rate is high enough to destroy every transmitted jpeg compressed orthophoto, we perform an image tiling before sending. Thus, only small parts of the image will be lost, if a bit error occurs. In case of

occasional or permanent loss of connection, the data uplink could be used to request for lost data. Besides, the data uplink could be used for the communication between airplane stuff and ground control station.

Airplane Antenna VT-002		Ground antenna VT-020	
Height	34cm	Height	>2.5m
Diameter	28cm	Diameter	2.0m
Antenna Gain S-Band	13dBi	Antenna gain S-Band	26dBi
Weight	<10kg	Weight	180kg
Datarate in the S-band	2x15MBit/s brutto, 2x10MBit/s netto (5 Watt, 2x16MHz licensed bandwidth)		
Range	Line of sight, appr. 100km		
Data interface	UDP		
Data loss	1:1e9 (not yet verified)		
Automatic alignment of both antennas			
Data uplink possible			

Table 1. Technical parameters of the microwave datalink
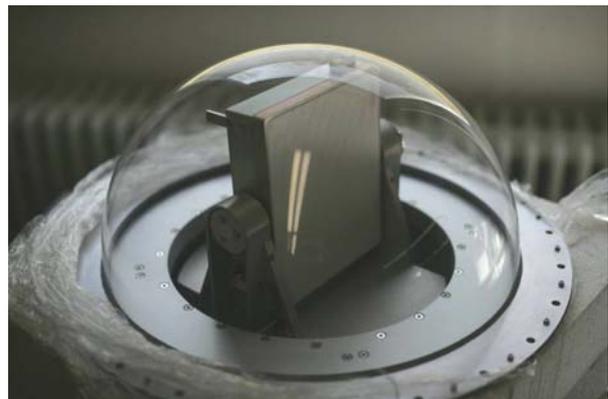
Figure 2. The microwave airplane antenna

2.4 Ground receiving and processing station

The mobile ground station consists of the autotracking microwave ground antenna, the ground part of the optical terminal, and several processing units for further processing and validation of the received data. The ground station must have a connection to the internet in order to send data to the portals. In Figure 4, possible connections between the ground stations to the internet are listed. As direct sight to the airplane must be provided, scenarios for the positioning of the ground stations are developed in cooperation with our national partners. Thus, the ground station must be positioned at elevated points and the next internet access point can be far away from the receiving ground station. In cooperation with the Federal Agency for Technical Relief (THW), scenarios for connecting the ground stations with the internet are developed and WLAN, UMTS,

directional radio and wired connection could be provided by the THW in case of natural disaster and mass events. The tools vary in range and data rate, e.g. directional radio can transmit data several kilometres in comparison to UMTS with a short range.

Figure 3. The microwave ground antenna
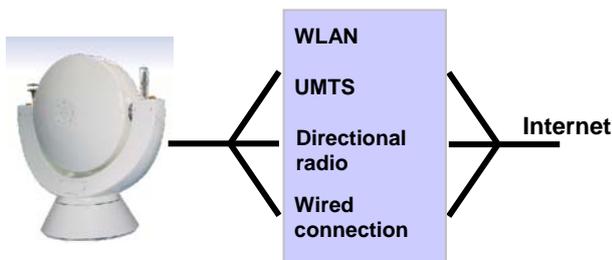
Figure 4. Possible connections to the internet

3. SYSTEM SOFTWARE

3.1 Middleware for distributed image processing

For near real time processing of 3K camera images, the onboard distributed image processing system on five PCs is controlled by the self developed middleware DANAOS (Thomas et al., 2009).

Each camera is connected via firewire to a PC which is responsible for image acquisition, for the orthorectication of images, and for the segmentation of roads supported by a priori knowledge of road axes from a road database. The fourth PC is responsible for the traffic processors which consist of two steps. These are the vehicle detection on segmented roads by edge extraction and boosting, and the vehicle tracking. The fifth PC controls the airplane microwave antenna and sends the processed data to the ground station.

In order to organize the real time modules the DANAOS middleware is running on each PC. The DANAOS middleware handles interprocess communication over the network, provides name services, and synchronizes access to shared memory. The middleware also supports the integration of different processes. For DANAOS, we have chosen a real distributed architecture with an efficient routing concept.

Following services are supported by DANAOS:
- Name-Services
- Message passing
- Shared memory communication
- Consumer/Producer Services

For small amount of data, message passing is supported by DANAOS, therewith it is possible to send all detected cars by message passing to modules in a ground station PC. Another example is when special interest points are detected in an image. These interest points can be sent to another module in the computer network.

The shared memory concept supports modules to exchange large data for instance image data without being copied explicitly. The middleware administrates all shared memories. A shared memory can be locked by any module. The type of lock can either be no writable or no readable or even both. If it is no readable e.g. if a module produces new image data, it will lock the image until writing is finished. Then it will unlock the image and all other modules can read or write the data. If another process has locked the data for writing no one else will obtain access to the image. If one module reads data, no locking is necessary. In cases where modules access the same shared memory and they are not running on the same machine, the access is quite difficult, but possible. DANAOS manages all shared memories in the network.

Figure 5 shows an overview of the distributed image processing system installed in the airplane.
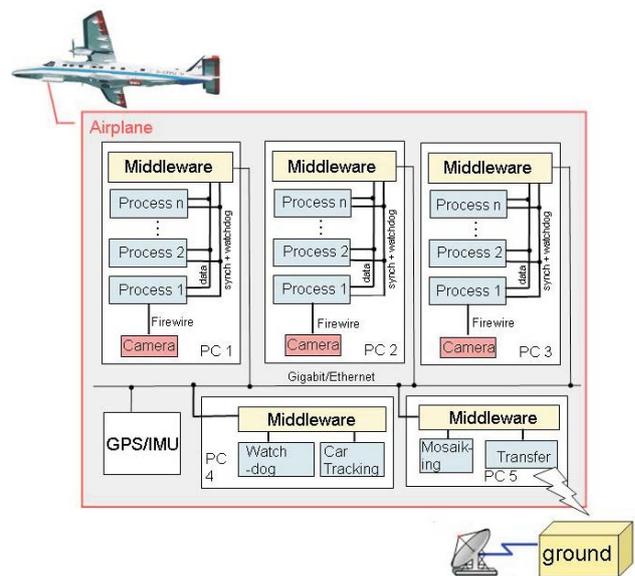

Figure 5. Architecture of the distributed airborne processing unit

3.2 Orthophoto processing

The orthorectification is based on a straight forward georeferencing using the GPS/IMU data, the camera calibration data, and an on-board available digital elevation model.

Within the framework of the DGPF project for the evaluation of camera accuracies (Cramer et al., 2009), a data acquisition campaign at the test site in Vaihingen/Enz was conducted. The aim was to validate

the accuracy of the 3K camera system at an independent test site. For this, a self-calibration bundle adjustment was performed on this data to assess the accuracy properties of the camera system and to (re)determine the interior parameters of the camera. The flight campaign was performed on 15th on July 2008 at the test site in Vaihingen/Enz. Table 2 lists the result of the accuracy of the 3K camera system at 61 check points (Kurz et al. 2007).

	Empirical RMSE (at 61 points)		Empirical RMSE (without systematics)
X	0.647 m	Max -1.166 m	0.331 m
Y	0.651 m	Max -1.787 m	0.380 m
Z	0.576 m	Max -1.702 m	0.527 m

Tab 2. Accuracy of the 3K camera system at check points

The accuracies reached by the direct georeferencing without using pass information are clearly worse in the magnitude of 2-3 meters, as here the IMU and the DEM accuracy, as well as the interior and boresight determination influence the accuracy.

3.3 Automatic image analysis for traffic parameter extraction

Main focus in the current development is the traffic processor, which extracts traffic information like traffic density and vehicle velocity from orthorectified 3K image sequences (Hinz et al., 2007, Rosenbaum et al., 2008, Reinartz et al., 2006). For traffic monitoring, the 3K camera system is in a recording mode, that we call "burst mode". In this mode, the camera takes a series of four or five exposures with a frame rate of 3 fps, and then it pauses for several seconds. During this pause, the plane moves significantly over ground. Then, with an overlap of about 10% to 20% to the first exposure "burst", the second exposure sequence is started. Continuing this periodical shift between exposure sequences and brakes, we are able to perform an area-wide traffic monitoring without producing an overwhelming amount of data.

3.3.1 Road segmentation

For an effective real time traffic analysis, the road surface needs to be clearly determined. The road extraction starts by forming a buffer zone around the roads surfaces using a road database as a basis for the buffer formation process. In the next step, two different methods for further feature analysis can be applied. Both modules automatically delineate the roadsides by two linear features. One module performs within the marked buffer zone edge detection as proposed by Phillipe Paillau for noisy SAR images (Paillau et al., 1997). With this method, mainly the edge between the tarry road area and the vegetation is found. The alternative module searches for the roadside markings by extracting lines on a dynamic threshold image. In this module, only the longest lines are kept representing the drawn through roadside marking lines. With the information of the roadside obtained in the processing step described before,

it is possible to restrict vehicle detections and tracking only to the well determined road areas.

As the extraction algorithms differ depending on the traffic density, a pre classification in free and congested traffic is performed first (Palubinskas et al., 2009). Then the detection algorithms differ as for free traffic the parameter extraction is based on the detection of single vehicle whereas for the dense traffic, the traffic parameters are derived based on image regions.

3.3.2 Free traffic

Our strategy for traffic monitoring from exposures obtained in "burst mode" is to perform a car detection only in the first image of an image sequence and then to track the detected cars over the next images. Canny edges in the segmented roads of the first image are grouped and classified into three parts which represent three main classes. These three classes are namely edges belonging to vehicles, edges belonging to roads, and edges within road and vehicle edges, and therefore not yet classifiable. Edges in the class with lowest steepness are ignored, while edges in the highest steepness class are directly assumed to be due to vehicles.

Then, potential vehicle pixels are grouped by selecting neighboured pixels. Each region is considered to be composed of potential vehicle pixels connected to each other. With the regions obtained a list of potential vehicles is produced. Using closed shapes, the properties of vehicle shapes can be described by their direction, area, the length and width. Furthermore, it can be checked if their alignments follow the road direction, and its position on the road can be considered as well. Results of the road and vehicle detection are illustrated in Figure 6 and the performance results of the vehicle detection are listed in Table 3. A boosting method for vehicle detection will be integrated in the future, which will improve the detection rate significantly.

Figure 6. Examples for road extraction (clipping from nadir images) and vehicle detection at free traffic. Upper panel shows line detections at a flight height of 1000 m, lower panel shows detected vehicles in the city area of Munich.

Site	Correct	False	Missed	Correct-ness	Complete-ness
Motorway (1000m)	85	22	41	79%	68%
Motorway (1500m)	67	32	19	68%	78%
Motorway (2000m)	95	30	76	76%	56%
City (1000m)	47	16	25	75%	65%

Table 3. Results on testing vehicle detection on data obtained at several test sites (from different flight heights). Counts of correct vehicle detections, false alarms and missed detections, as well as correctness and completeness in percentage are given.

3.3.3 Dense traffic

The traffic parameter extraction in dense traffic is based on the calculation of disparities between the segmented roads in two orthorectified overlapping images. For this, the images have to be transformed to a "quasi" epipolar image, so that corresponding image rows are relatable and aligned to the road direction. The disparities of corresponding points can be rated as shift vectors between the vehicles of two images. With the knowledge of the pixel resolution on ground and the time difference between two images, the average speed on road segments can be calculated by the disparities (Zeller et al. 2009).

4. END USER REQUIREMENTS

The requirements of different BOS and rescue forces for a near real time airborne monitoring system were integrated in the first prototype system, which should be ready in the middle of 2009. The most important requirements of end users are summarized:

- Up-to-date aerial images (Printed and online)
- Acquisition of area wide traffic situation
- Determining the accessability and reachability of roads
- Monitoring of assembly areas of the rescue forces
- Automatic generated damage layers (Flood, Fire)
- Change detection (3D)

National cooperation partners are the Federal Office of Civil Protection and Disaster Assistance (BBK) and the Federal Agency for Technical Relief (THW) supplemented by different regional BOS institutions in the two demonstration regions Cologne and Munich.

5. RAPID FLIGHT STRIP PLANNING

The future plan is to operate a quickly reacting mobile ground station and an airplane on standby for monitoring of natural disasters and mass events. The activation of the airplanes should be as fast as possible in order not to loose the edge over the satellite data.

For this, concepts for the quick alerting of the airplanes and the activation of the ground station were prepared, which includes the application for the flight clearance as well as the communication between cooperation partners and the ground station.

The following steps must be performed after the alarming but before take-off:

- Alarming the operators and pilots, preparing the airplane and sensors
- Collecting the regions and roads to be monitored from the end users
- Planning of flight strips regarding to the user requirements
- Application for the flight clearance

After take-off the following steps can be performed:

– On-the-fly order of already planned flight strips
– On-the-fly flight strip planning regarding to the user requirements

As communication interface between the end-user and the airplane, the DLR traffic portal will be used. Here, the end-user can mark regions of interest and select already planned flight strips. The information will then used to modify planned flight strips or to plan new flight strips by the operators.
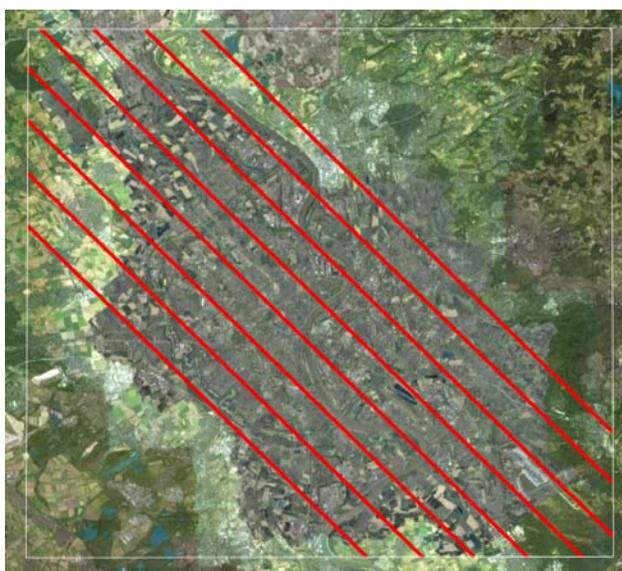
Figure 7. Pre planned flight strips provided to the end user for quick ordering of up-to-date images and traffic data (Example Cologne).

Then, the coordinates will be sent to the airplane. Figure 7 shows an example of pre planned flight strips for the city region of Cologne. Based on eight strips the whole city can be covered by the 3K camera system with 15cm ground sampling distance. The acquisition time would be around one hour for all strips. Thus, it would be desirable to reduce the number of flight strips according to the user needs.

6. CONCLUSIONS

Airborne rapid mapping for disaster and traffic monitoring is an interesting research field and technically challenging. The overall processing chain is on the edge of the technically feasible with respect to the data rates at the camera, at the processing units in the airplane, and the data downlink. Focus in the development lies on the increase of the processing speed in particular for the applied traffic extraction algorithms and the orthophoto processing. The bottleneck in the data rate is the microwave downlink in the S-Band (~20MBit/s) and the orthophoto processing (~30MBit/s). When comparing this data rates with the data rate at the cameras of around 100MBit/s, the need for data reduction by onboard processing is quite visible.

All in all, the first prototype of the system will be ready in the middle of 2009 and the validation process of the system will then continue.

7. REFERENCES

Thomas, U., Rosenbaum, D., Kurz, F., Suri, S. and Reinartz, P., (2009). A new Software/Hardware Architecture for Real Time Image Processing of Wide Area Airborne Camera Images. *Journal of Real-Time Image Processing*, Springer, 4 (3), 229-224.

Cramer, M., Krauß, H., Jacobsen, K., von Schönermark, M., Haala, N., Spreckels, V., (2009). Das DGPF-Projekt zur Evaluierung digitaler photogrammetrischer Kamerasysteme, *DGPF Tagungsband 18 / 2009*. DGPF Jahrestagung 2009, Jena, Germany

Kurz, F., Müller, R., Stephani, M., Reinartz, P., Schroeder, M. (2007). Calibration of a wide-angle digital camera system for near real time scenarios. In: *ISPRS Hannover Workshop 2007,* Hannover, June 2009, ISSN 1682-1777

Hinz, S., Kurz, F., Weihing, D., Suchandt, S., Meyer, F., Bamler, R. (2007). Evaluation of Traffic Monitoring based on Spatio-Temporal Co-Registration of SAR Data and Optical Image Sequences. *PFG,* 5/2007,. 309-325.

Rosenbaum, D., Kurz, F., Thomas, U., Suri, S., Reinartz, P. (2008). Towards automatic near real-time traffic monitoring with an airborne wide angle camera system. *European Transport Research Review, 1,* Springer, ISSN 1867-0717.

Reinartz, P., Lachaise, M., Schmeer, E., Krauss, T., Runge, H., 2006. Traffic monitoring with serial images from airborne cameras, *ISPRS Journal of Photogrammetry & Remote Sensing 61 (1)*, 149-158.

Paillau, P. (1997). Detecting Step Edges in Noisy SAR Images: A New Linear Operator. *IEEE Transactions on Geoscience and Remote Sensing,* Vol. 35, No.1, pp. 191-196

Zeller, K., Hinz, S., Rosenbaum, D., Leitloff, J., Reinartz, P. (2009). Traffic monitoring without single car detection from optical airborne images. In: *ISPRS Hannover Workshop,* June, 2009, Hannover, Germany.

Palubinskas, G., Kurz, F., and Reinartz, P., (2009). Traffic congestion parameter estimation in time series of airborne optical remote sensing images. In: *Proc. of ISPRS Hannover Workshop 2009* ,June, 2009, Hannover, Germany.