

Real Time Airborne Monitoring for Disaster and Traffic Applications

P. Reinartz, D. Rosenbaum, F. Kurz, J. Leitloff, O. Meynberg

German Aerospace Center (DLR), Remote Sensing Technology Institute, PO Box 1116, D-82230 Weßling, Germany – (peter.reinartz, dominik.rosenbaum, franz.kurz, jens.leitloff, oliver.meynberg)@dlr.de

Abstract – Remote sensing applications like disaster or mass event monitoring need the acquired data and extracted information within a very short time span. Airborne sensors can acquire the data quickly and on-board processing combined with data downlink is the fastest possibility to achieve this requirement. For this purpose, a new low-cost airborne frame camera system has been developed at the German Aerospace Center (DLR) named 3K-camera. The pixel size and swath width range between 15 cm to 50 cm and 2.5 km to 8 km respectively. Within two minutes an area of approximately 10 km x 8 km can be monitored. Image data are processed onboard on five computers using data from a real time GPS/IMU system including direct georeferencing. Due to high frequency image acquisition (3 images/second) the monitoring of moving objects like vehicles and people is performed allowing wide area detailed traffic monitoring.

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

1. INTRODUCTION

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 (EU – FP7) try to fill this gap and enforce the application of airborne rapid mapping in case of natural disasters but also for mass events. In the projects VABENE and SAFER, airborne rapid mapping systems are developed and validated together with the national rescue forces and security related forces in Germany. In the VABENE project, a DLR traffic portal is developed to equip the forces with powerful tools like traffic prognosis and traffic routing supported by the data from the rapid mapping system. The development of these systems is close contact with the national rescue and security related forces. The first prototype of the rapid airborne mapping system is already available.

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 are summarized.

2. SYSTEM OVERVIEW

The real-time remote sensing system consists of two parts. One part is installed onboard the aircraft, consisting of the 3K camera system, a real-time GPS/IMU unit, one PC for each single camera processing image data, one PC for traffic monitoring tasks, a downlink-antenna with a band width of 5 Mbit/s (actual, upgradeable to a bandwidth of about 20 Mbit/s)

automatically tracking the ground station, and a PC for steering the antenna and feeding the downlink with data. The ground station mainly consists of a parabolic receiving antenna, which is automatically aligned with the antenna at the aircraft, and a PC system for visualization of the downlinked images and traffic data. Given an internet access at the place of the ground station, the obtained aerial orthoimages and traffic data will be directly transferred to the security and emergency authorities.

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, Figure 1). 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 $104^{\circ}/31^{\circ}$ 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 direct georeferencing. The ability to acquire image sequences with up to 3Hz broadens the spectrum of possible applications in particular to traffic monitoring.

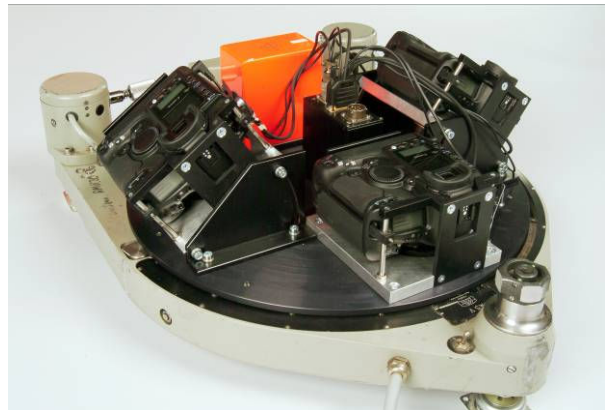


Figure 1. DLR 3K-camera system consisting of three Canon EOS 1Ds Mark II, integrated in a ZEISS aerial camera mount. Orange box is the IGI inertial measurement unit for measuring flight attitude enabling direct georeferencing.

2.2 Airborne processing units

The high input data rate on the one hand and the processing intensive modules on the other hand put high demands on the on-board image processing hardware, which consequently leads to a multihost solution with five PCs in total (Figure 2). All of them run 32bit-Windows XP due to the fact that some of the third-party software we use in our processing system only

supports Windows. Each camera is connected via Firewire IEEE 1394a to a dedicated host. It streams the images directly without memory card buffering to the camera PCs (PC1 - PC3).

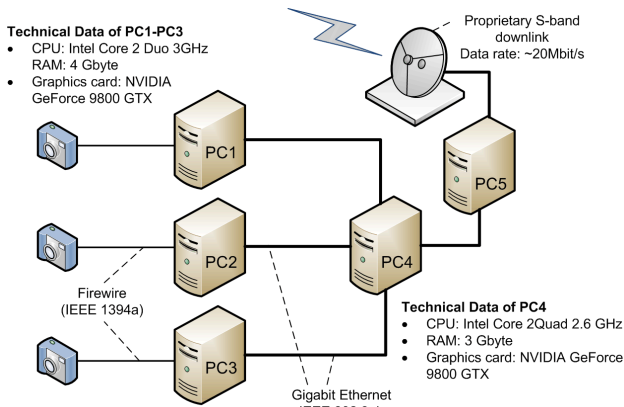


Figure 2. Topology of the onboard network part installed at the aircraft. Each camera is directly connected to PC1,2,3 which perform georeferencing and orthorectification. Thematic image analysis like vehicle detection and tracking for traffic monitoring takes place at PC4. PC5 sends the results and georeferenced orthoimages via a proprietary S-band transmitter to the ground.

The EOS Digital Camera Software Development Kit (EDSDK) is installed on each of these hosts and provides a C language interface for the control of the cameras and the download of images to the host PC. Since the orthorectification and georeferencing process needs the exact position and orientation of the airplane, the IGI aerocontrol RT GPS/IMU system is connected via Ethernet to the onboard system. The fibre-optic gyro based Inertial Measurement Unit with its integrated 12-channel L1/L2 GPS receiver are triggered by the cameras external flash signal. A module in the software matches the received geo-data with the image received from the camera. The image is written to disk where it can be read by the orthorectification module. The geo data is sent to this module via message passing. After the orthorectification process (Müller et al., 2002) has completed, the orthorectified image is written to disk, copied to PC 4 and could be processed for automatic traffic data extraction or for further thematic interpretation by additional automatic image analysis modules. PC 5 steers the downlink antenna and streams the image data that should be send to the ground to the HF components of the radio link. The processed data are transmitted to a ground station using a commercial auto-tracking microwave downlink in the S-band with a data rate of approx. 20Mbit/s and a range of 100km. Thereby, 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.

2.3 System at ground station

The mobile ground station consists of the autotracking microwave ground antenna, and three 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 user portal. One ground station PC is used for steering the ground antenna and receiving data. Another PC is used for recomposing the tiled images. The third PC provides an

image viewer and several image processing tools and is used for validation purposes and for the transfer to the user portal via internet.

The data received by the ground station are further processed and distributed directly to the users. These are national cooperation partners like the German Federal Agency for Technical Relief (THW) supplemented by several regional civil security institutions in Germany.

3. APPLICATION EXAMPLES IN CASE OF DISASTER OR MASS EVENTS

3.1 System at ground station

With its high resolution and its high image repetition rate (that results in a high overlap of successive images) the 3K camera system is well suited for 3D analysis. For generating digital surface models (DSMs) the 3K camera is operated in a continuous image recording mode with a high image repetition rate of 2 Hz. This leads to an overlap of 96% of nadir images at a typical flight height of 1500m above ground for this application. In order to decrease holes in DSM generation due to shadowing effects the region of interest is normally covered by at least two perpendicular flight strips. Recorded 3K Images are transferred to epipolar geometry and analysed with a semi-global dense matching algorithm (e.g. Zhu et al. 2010). In order to increase processing performance the matching algorithm is implemented in a version for the execution on Graphic Processing Units of the manufacturer NVIDIA. For that the graphic library "CUDA" is used. The accuracy of the produced DSM depends upon basis length of the matched images. At an optimal basis length of 150m (that results in an overlap of 80 %) a relative accuracy for DSM heights of better than 1m is achieved. The system was successfully deployed for the 3D analysis of the landslide that happened at Nachterstedt (Germany) at July, 18. in 2009. During this disaster with three fatalities a hillside slid down into a quarry pond at a length of 350m and destroyed two houses. The situation prior to and after the landslide is shown in Figure 3.



Figure 3: Map of the situation at Nachterstedt prior to (left) and after the landslide (right). It was produced at DLR Center for Satellite Based Crisis Information (ZKI). Right part shows a mosaic of 3K camera aerial images. Red line shows the landslide border, blue line marks the original and purple line the new waterside border. Yellow line is the approximate border of the slope.

Left image was taken prior to the landslide. The right part of the map was recorded with the 3K camera and shows the affected area four days after the landslide appeared. Figure 4 shows a difference image of DSMs prior to and after the disaster. The height difference is color coded according to the color wedge attached with blue colors marking areas with only low height difference up to red colors marking places with highest height difference. Coordinates and height differences in this figure are given in units of meter. From this data the landslide volume was measured to be 1.4 million cubic meter.

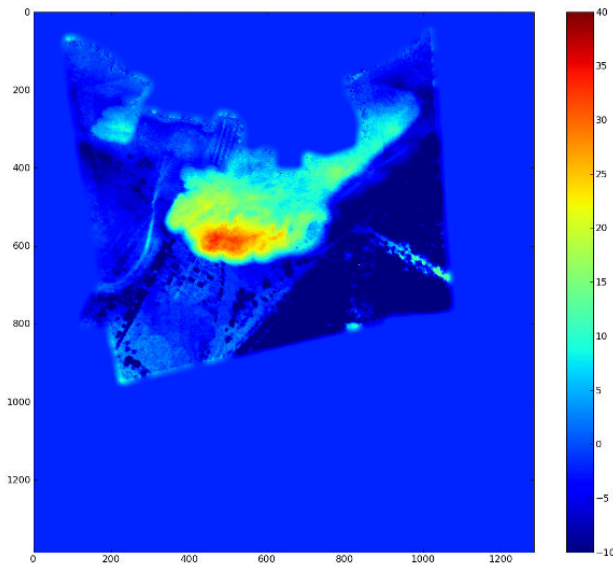


Figure 4: Difference image of affected landslide area in Nachterstedt generated from 3K camera 3D analysis. The difference between DSM produced from 3K camera images after landslide and a reference DSM (recorded prior to the disaster) is shown (from Tao 2009). The height difference is color coded with red being the highest difference. From this the volume of affected landslide area was calculated to be 1.4 million cubic meter.

3.2 Automatic Traffic Data Extraction

Traffic monitoring from aerial 3K camera images is reasonable during mass events or crisis situations that justify the high costs during operation. In case of mass events it delivers additional traffic data of all road categories in the area of interest and is not limited to main roads like ground sensor networks. This data can be used for routing of security forces and emergency units and delivers valuable information to operation controllers.

For traffic monitoring aerial images are recorded in a special mode called burst mode. Each image burst consists of 3-5 images taken with a high repetition rate of up to 3 Hz. In order to keep the data amount as low as possible, no image data is recorded between to bursts. Within this break the plane moves over the ground, until a new region is in sight the field of view of the cameras. A typical break lies between 5-7 seconds depending on flight height and airspeed. For automatic traffic data extraction each image burst is processed separately. Processing starts with vehicle detection on the first image of each image sequence (burst) followed by a vehicle tracking based on template matching between the image pair consisting of the first and second image of the sequence.

With this strategy the traffic parameters flux and density can be derived from aerial image sequences. Vehicle detection

performed on the first georeferenced image of the sequence gives the vehicle density whereas vehicle tracking applied on all consecutive (georeferenced) image pairs gives the velocity of the vehicles so that the flux of the traffic can be calculated.

Vehicle detection is performed by the application of two classifiers to the first image of each sequence with the use of a priori knowledge of the rough position of the roads inside the image obtained from a road database. The classifiers are based on the algorithms AdaBoost and SVM and were trained offline by a training dataset consisting of (aerial) thumb images of 3000 vehicles and more than 10000 negative examples. We obtain a classification quality of more than 80 % (Rosenbaum et al., 2010) even in complex scenarios like downtown areas.

Vehicle tracking between two consecutive images of the burst is done by template matching based on normalized cross correlation. At each position of a detected vehicle in the first image of the image sequence a template image is created. Then in the second image of the sequence a search space for this vehicle is generated depending on the position of the vehicle in the first image, driving direction obtained from a road database, and the expected maximum speed for the road plus a certain tolerance. Within that search space, the template is correlated and the maximum correlation score is stored in connection with the template position within the maximum appeared. This represents the found match of each vehicle in generally. The correlation is done in RGBcolor space. Since all images are stored with their recording time, vehicle speed can directly calculated from both the position of the vehicle detected in the first image and the position of the corresponding match in the second image. Then, vehicle tracking is applied to the following image pair of the sequence. Vehicle tracking performs well with a quality of 90-95 % (Rosenbaum et al., 2010). Figure 5 shows traffic data automatically recorded from aerial images during the mass event "BAUMA exhibition" at Munich exhibition center on April 24, 2010. A traffic congestion on the motorway A94 near exit exhibition center can be seen. The velocity of the vehicles is coded in the color of the triangles (according to the legend) that mark each vehicle detection in the image. Quality of traffic data is about 80%.

The quality of traffic data extracted automatically from 3K camera aerial images is about 75% (Rosenbaum et al., 2010). This makes the system competitive to that of ground based sensor networks. The quality of a typical induction loop is better than 90% (e.g. Leonhardt, 2004) at time of production. During years of continuous operation it decreases slowly. In a complete sensor network of a metropolitan area there is a mix of new and older sensors, and some of them have even failed completely. This drops down the average quality or system accuracy of the sensor network. In Munich, the system accuracy of the complete ground based sensor network for traffic data acquisition is at a value of 80%, as stated by Munich integrated traffic management center. The quality of traffic data obtained by the presented remote sensing system being competitive to that of road sensor networks in connection with the good spatial resolution (including minor roads) and the reliability in case of ground damage makes the system well suited for its operation during mass events and disasters. A simulation for traffic prognosis in case of mass events and disaster is currently under development (Behrisch et al., 2008) and will be feed with traffic data extracted from 3K aerial images in the near future performing a data fusion of that data with conventional data available like that of induction loop networks or floating cars (e.g. Busch et al. 2004).

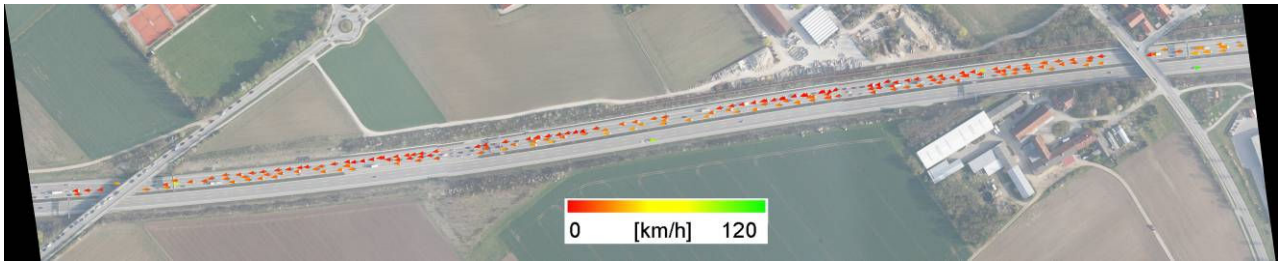


Figure 5: Traffic data extracted automatically by the processing chain on BAUMA campaign 2010 near exit "Munich exhibition center" of motorway A94. Quality of traffic data is 80% in case of that campaign. Periodic gaps in traffic data are due to missing overlap between image bursts (which can be corrected easily by flight planning in future campaigns).

4. CONCLUSION AND FURTHER WORK

Beyond all the possible applications that are provided by the rapid mapping capabilities of the system, it is dedicated to 3D analysis. DSMs obtained from image data recorded by the system possess a height resolution in z-direction of better than 1 m. Therefore the system is well suited for the application in disasters like landslides, earth quakes and similar scenarios that require 3D analysis.

The quality of traffic data obtained by the presented remote sensing system being competitive to that of road sensor networks in connection with highest spatial resolution (including minor roads) and the reliability in case of ground infrastructure damage makes the system also dedicated to traffic monitoring applications during mass events and disasters. Its traffic data accuracy is comparable to that of typical metropolis ground based sensor networks with the advantage of the remote sensing system, that traffic data on all road categories (including smallest minor roads) can be recorded. For example in case of traffic congestion on main roads and motorways also densities on nearby alternative routes (that are commonly not covered by induction loops or stationary traffic cameras) can be determined.

However, the operating costs of this prototype system are quite high which limits its use to short time scenarios like mass events or disasters. With the ongoing development of UAV or HALE (High Altitude Long Endurance) unmanned aircrafts, further applicability of a similar system, after it has been refurbished to a low weight solution, may be possible in future.

References

Behrisch, M., Bonert, M., Brockfeld, E., Krajzewicz, D. and Wagner, P., 2008. Event traffic forecast for metropolitan areas based on microscopic simulation. In: Third International Symposium of Transport Simulation 2008 (ISTS08), Queensland, Australia.

Busch, F., Glas, F. and Bermann, E., 2004. Dispositionssysteme als FCD-Quellen für eine verbesserte Verkehrslagerekonstruktion in Städten - Ein Überblick. Straßenverkehrstechnik Vol. 09

Leonhardt, A., 2004. Detektortest siemens ld4. Technical report, TU München <http://www.siemens.nl/ITS/getfile.asp?id=52>.

Müller, R., Lehner, M., Reinartz, P., Schroeder, M. and Vollmer, B., 2002. A program for direct georeferencing of airborne and spaceborne line scanner images. International

Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, ISPRS Comm. I, Vol. XXXIV, part 1

Rosenbaum, D., Leitloff, J., Kurz, F., Meynberg, O. and Reize, T., 2010. Real-time image processing for road traffic data extraction from aerial images. In: ISPRS Technical Commission VII Symposium 2010.

Steger, C., 2001. Similarity measures for occlusion, clutter, and illumination invariant object recognition. In: B. Radig and S. Florczyk (eds), Pattern Recognition, Lecture Notes in Computer Science, Vol. 2191, Springer-Verlag, Berlin, pp. 148– 154.

Tao, J., 2009. Generierung von 3d-Oberflächenmodellen aus stark überlappenden Bildsequenzen eines Weitwinkelkamerasystems. Master's thesis, DLR - German Aerospace Center / University of Stuttgart.

Zhu, K., Butenuth, M. and d'Angelo, P., 2010. Computational optimized 3D reconstruction system for airborne image sequences. In: International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, ISPRS Comm. III, Vol. XXXVIII, part 1