THE DPA-SENSOR SYSTEM FOR TOPOGRAPHIC AND THEMATIC MAPPING

Michael Hahn, Dirk Stallmann, Christian Stätter
Institute of Photogrammetry
Stuttgart University
D-70049 Stuttgart / Germany

Franz Müller
Daimler-Benz Aerospace AG
Dynamics Systems
D-81663 Munich / Germany

ISPRS Commission II, Working Group 1

KEY WORDS: Real-time mapping, digital data collection, DPA - Digital Photogrammetric Assembly, integrated sensor system, topographic and thematic mapping

ABSTRACT

The Digital Photogrammetric Assembly (DPA) is an integrated airborne sensor system for real-time data collection. The camera module consists of three panchromatic line arrays for stereo imaging and four line arrays for multispectral imaging. For georeferencing the system is provided with an INS and can be synchronized with a GPS sensor. This paper is concerned with the evaluation of the DPA with respect to its potential and efficiency for topographic and thematic mapping. We focus on the photogrammetric tasks of georeferencing and image rectification and present results obtained by multispectral image analysis. Some expectations on future investigations into 3D reconstruction using context supplied by the multispectral data will be given in the outlook.

1. INTRODUCTION

For several years increasing interest of research institutions and private companies in utilizing mobile mapping systems for digital data collection can be observed. Highly attractive are those systems because they aim at fast collection of digital data, for example, for input into Geographic Information Systems (GIS). The systems are designed to be put on landborne and airborne platforms. Common to all systems is that at least two types of sensors are integrated: one for positioning and one for imaging. In the case of landborne systems this is a selection of GPS (Global Positioning System), INS (Inertial Navigation System), odometer, digital and analog video, radar, imaging laser and other sensors. Mostly used imaging sensors of the airborne systems are CCD line and frame cameras, laser scanners and radar which are combined with GPS and INS for continuous absolute positioning and for determination of absolute or relative attitudes of the platform.

With respect to economic aspects inquiry of users is on versatility and cost effectiveness of those systems. Very high are the requirements on the data collection technologies for massive database production. At present the most important application fields for the landborne systems are inventory of highways, railroads and monitoring of utilities. The airborne systems focus on the cartographic market. Here is a wide spectrum of all kind of interpretative applications. Photogrammetric 3D restitution techniques can used for supporting topographic and thematic mapping of high spatial resolution and accuracy. Depending of the multispectral component of those sensors application fields like vegetation mapping, environmental monitoring and geology are more and more connected to photogrammetry.

The DPA is a line array (pushbroom) scanner system developed for airborne application. Today a considerable number of pushbroom scanner systems exist. Examples are the

- Compact Airborne Spectrographic Imager (CASI) of Itres Research Ltd., Calgary, Canada (Kramer, 1994)
- Multi-detector Electro-optical Imaging Sensor (MEIS) build by MacDonald Dettwiler and Associates of Vancouver, Canada, for the Canada Centre of Remote Sensing (Gibson, 1994)
- Wide Angle Airborne Camera (WAAC) of the German Aerospace Research Establishment DLR – Institute of Space Sensor Technology, Berlin, Germany (Eckardt, 1995)
- Three-Line Scanner (TLS) build by Core Co. Ltd., Tokyo, Japan (Murai et al., 1995)

In this scanners at least three or more CCD arrays are mounted on the focal plane. In the CASI this is technically solved by a frame transfer CCD. With each array a line image of the scene below is recorded. The aircraft motion provides the scanning in the forward direction.

CASI and MEIS are commercially available multispectral instruments. CASI has 288 spectral detector lines of 512 pixel per line which cover the visible and near infrared spectrum. In spectral and spatial recording mode this gives 39 and 15 bands, respectively. In addition to the imaging mode, the CASI can also operate as a multi-point spectrometer. The MEIS imager covers a similar spectral range but with 8 spectral channels of 1024 output pixels each. By adding external mirrors to two of the channels a forward-looking and an aft-looking channel can be created which provides single-pass stereo coverage.

TLS and WAAC are new three CCD-line scanners for photogrammetric applications. The cameras with 7500 (TLS) and 5184 (WAAC) pixels per CCD line allow for recording the scene with a ground pixel size of 10 cm (TLS) and 1.6 m (WAAC). Both systems are using GPS and INS sensors for continuous positioning and attitude determination.

The DPA sensor system is a combination of a photogrammetric and a multispectral airborne instrument. We want to discuss more details on the system in the next section. Our task is to evaluate the system with respect to its potential and efficiency for photogrammetric-thematic applications. For that purpose a test flight experiment was carried out (section 3). Results on georeferencing, image rectification and multispectral image analysis are presented in section 4. Some expectations on work done next will be given in the outlook.

2. THE DPA SENSOR SYSTEM

The DPA system is developed by the Daimler-Benz Aerospace AG (DASA), formerly the MBB GmbH. The camera consists of three panchromatic CCD line arrays for in-flight stereo imaging (stereo module) and four CCD line arrays for multispectral imaging using exchangeable filters (spectral module). The fundamental idea of the system is to get single-pass stereo coverage and multispectral coverage of a scene by recording all seven channels of stereo and multispectral data simultaneously.

The stereo images are taken with a convergence angle of $\pm 25^0$ between the nadir-looking array and the forward-looking or backward-looking arrays. All CCDs are Fairchild sensors with 6 000 detector elements in each line. The CCD arrays of the stereo module were optically buttoned using double lenses which gives a wide-angle geometry with a width of 12 000 pixels for the stereo channels. The field of view of the spectral and the stereo module are the same which is obtained by adjusting the focal lengths of both modules. Some more basic camera data are summarized in table 1.

Table 1: Basic camera parameter

Module	**Stereo**	**Spectral**
Focal length [mm]:	80	40
Line array [pixels/line]:	12000	6000
Data resolution [bit]	8	8
Field of view:	$\pm 37^0$	$\pm 37^0$
IFOV [mrad]:	0.125	0.250
Convergence angle:	$\pm 25^0$	
Spectral range [nm]:	515–780	440–525
		520–600
		610–685
		770–890

Connected to the optic module is an INS containing turn rate gyros and accelerometers. The synchronized registration of the line image data with the gyro and accelerometer data is a prerequisite for measuring aircraft motion parameters. Processing the inertial data leads to position and attitude of each image line with a high relative accuracy.

What was missing in DPA so far is the integration with GPS. The current evaluation of the system was now the occasion for adding a GPS receiver to the DPA recording system as indicated in figure 1. Time synchronisation with the GPS is solved by transmitting pulses of each multiple of 1024 recorded image lines. This time stamps send by the DPA can be directly registered by the GPS receiver. To be more flexible in linking further sensors, e.g. a classical aerial camera, we added a multisensor synchronisation board using a PC laptop computer.

Another component of the DPA instrument is the stabilization platform on which the camera together with the INS is mounted. Here a SM2000 platform supplied by Carl Zeiss Jena is used. For data storage of image and supplementary data an AMPEX High Density Digital Tape (HDDT) recorder with a data rate of about 110 Mbit per second is used.

The recording system is operated via a standard terminal using menu input. There is a online display of recorded image on a video screen which allows for checking of image brightness, camera yaw correction and flight speed with respect to line frequency.

The geometric and radiometric calibration of the system is of general importance for all kind of digital photogrammetric processing. A renewed geometric calibration of all seven channels was performed in laboratory by DASA using a collimator and a precision two-axis angular indexing table. With that the channels can be co-registated and corrected for lens distortions. For normalisation of the response of each channel radiometric calibrations are performed. The radiometric correction is directly taken into account during data recoding.

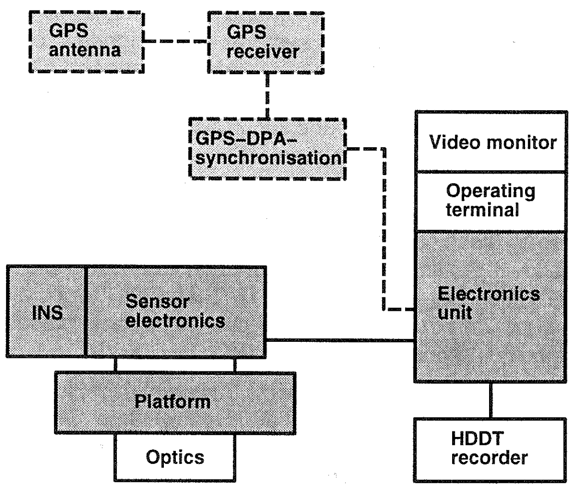

Figure 1: DPA recording system

3. TEST FLIGHT MÜHLACKER-VAIHINGEN

For the experimental evaluation of the DPA a test flight experiment was carried out in 1995. Parameters of this flight are listed in table 2. This test area Mühlacker-Vaihingen was chosen because topography and land-use of this area are well suited for photogrammetric and thematic investigations. The small distance (20 km in northwest direction) between the test area and Stuttgart (Germany) was benefical for the organisation and field work of this test.

Table 2: Parameters of the test flight Mühlacker-Vaihingen

Area:	4.5 km × 7 km
Flying height above ground:	2300 m
Velocity of aircraft:	70 m/s
Scan frequency:	235 Hz
Ground pixel size of	
stereo images:	0.30 m
multispectral images:	0.60 m
Date of flight:	26.07.1995

The test flight was performed together with Kirchner and Wolf Consult, Hildesheim. An aircraft equipped for carrying two camera systems simultaneously was used which allowed for taking DPA images and aerial images with the RMK TOP 15 during the same flight. For our investigations this gives us the opportunity to compare the quality of photogrammetric restitution using the DPA with the results found by the classical photogrammetric techniques using aerial images. For having ground truth data about 200 signalized points have been spread out in the test region. For that purpose white PVC-plates have been used and white paintings are drawn on ground with a size of 1×1 m^2. The scene is captured by three strips flown in east-west direction and three strips in north-south direction. The neighbouring strips have a side overlap of 60 percent.

The scheme for processing the DPA data of this flight experiment is shown in figure 2. Computations with the 1 Hz GPS data are carried out using standard software packages. Position and attitude determination from the INS data is solved within the DPA system which also serves for HDDT conversion of the recorded data. The other two boxes in figure 2 deal with GPS-INS integration and image rectification. For these tasks software has been developed. The results of this processes are presented in the next section.

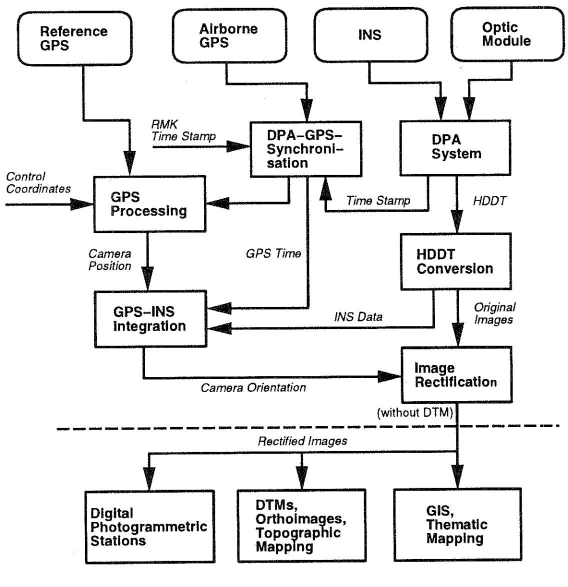

Figure 2: DPA test flight processing scheme

The intersecting line between DPA specific data processing with the upgrade of raw data and the application dependent further use of processed data is currently drawn at the end of the image rectification process. The rectified images can be introduced into Digital Photogrammetric Workstations where stereo viewing supports the measurement processes. Stereo impression is quite bad with the directly recorded image data even though a stabilized platform is used. The rectified image data can be processed further with line triangulation modules for 3D recovery or with DTM packages, for example, the MOMS algorithms (Fritsch et al., 1995) for DTM reconstruction. The georeferenced multispectral and panchromatic images are of increasing importance as a source for GIS. Our interest is in topographic and thematic mapping with the DPA data where a lot of research has to be done in fusing the data and the evaluation and interpretation techniques to exploit the potential of the DPA sensor.

4. PHOTOGRAMMETRIC-THEMATIC PROCESSING

In this section we present experiences with georeferencing and image rectification of DPA stereo images and discuss first results obtained by multispectral analysis of the spectral DPA channels.

4.1 GPS-INS Integration

The INS is required to measure the high frequency translational and rotational motion parameters of the airborne sensor. Because the optic module is put on a stabilized platform only angular movements are recorded which are not compensated by the platform. A plot of the attitude rates is shown in figure 3. Quite easy to see are a few sharp peaks with an amplitude of 0.015^0 at 235 Hz or 3.5^0/sec. This high changes of the attitudes can only be explained by rotational aircraft motion passing over the compensation interval (of around $\pm 5^0$) in which the platform is fully operational.

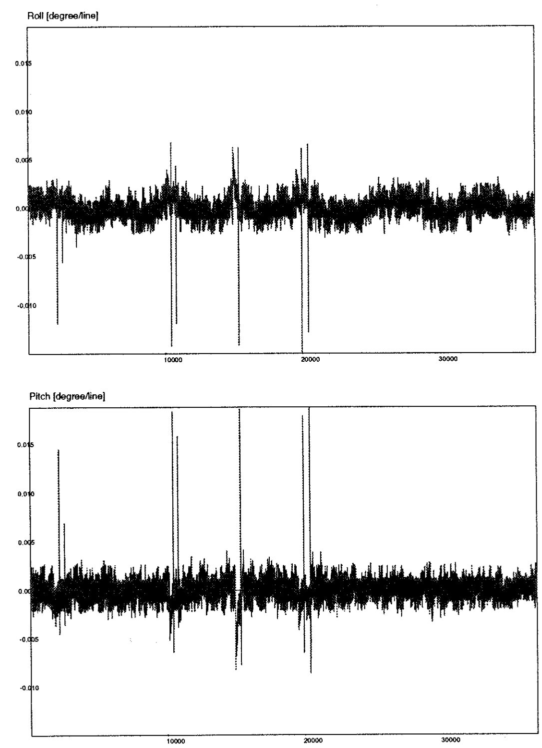

Figure 3: Attitude rates (roll and pitch) of one strip

For georeferencing of airborne sensors the GPS-INS integration is considered to be the most powerful technique.

"The integration of inertial and GPS satellite techniques currently offers the best potential for implementing georeferencing systems..." (Schwarz, 1995). GPS has long term stability with an accuracy of one or two decimeters if Differential GPS (D-GPS) is applied. The INS has a high relative accuracy for the derived position and attitudes but because of the integration process drift can not be avoided.

The design of a Kalman filter is considered to be the most promising technique for GPS-INS integration. Because in our case existing tools for an independent processing of D-GPS and INS are used we decided to choose a more pragmatic solution to exploit D-GPS for eliminating drift in INS positioning. This is done by the following steps:

1. Estimate approximate INS drift parameters by using polynomials.

   For modelling the attitude drifts a first order polynomial was sufficient. But for the position a fourth order polynomial has given the best results. This indicates that the initial alignment of the INS body frame with the computational frame was not satisfactory.

2. Determine the datum transformation between the GPS and the INS coordinate frame and adjust the high frequency (235 Hz) INS data to the low frequency (1 Hz) GPS data.

   The datum transform is solved by 7 parameter transformation. After that GPS and the residuals between GPS and INS are given in the local INS frame. This residuals are used for a refined adjustment of the INS data to the GPS trajectory.

The result of this processing is illustrated in figure 4. The plot shows the resulting height component for a part of one strip.

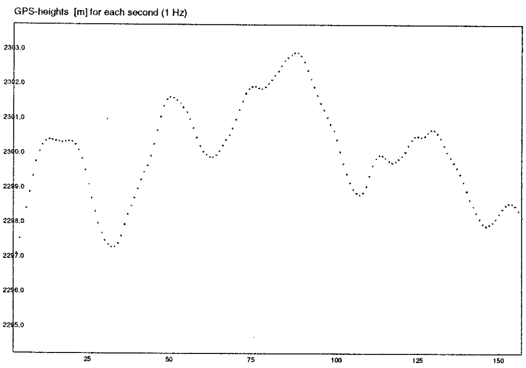

Figure 4: Height–component of a part of the flight path

4.2 Image Rectification

The recorded images displayed by small parts in figures 5 and 7 show distortions which are mainly caused by attitude variations. Correcting for this movements is done by using the orientation of each line derived from the GPS-INS data as described above.

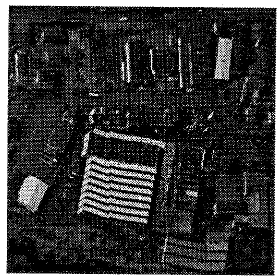

Figure 5: Original image (1024^2 Pixel)

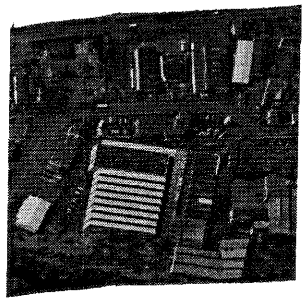

Figure 6: Rectified image

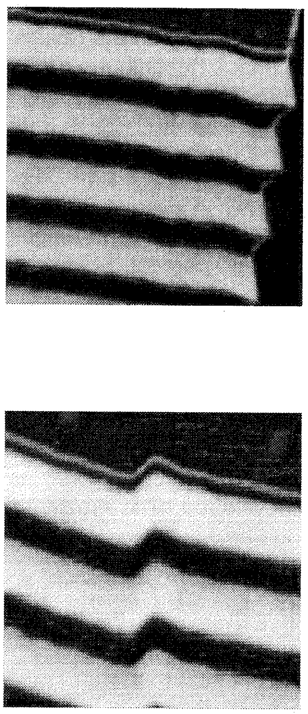

Figure 7: Zoom of original image (upper row 144^2, lower row 96^2 Pixel)

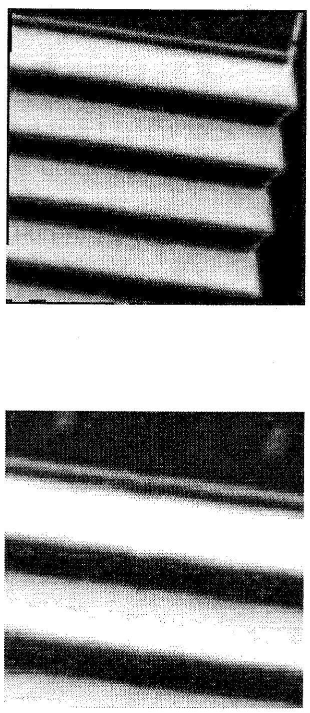

Figure 8: Zoom of rectified image

A rectification plane perpendicular to the height axis of the local coordinate system is defined. This horizontal plane is located in a mean flying height above ground (Z-plane). Then "approximate vertical" images are produced based on the direct method for image rectification as indicated in figure 9. Each pixel in the image space is projected on the Z-plane by using the orientation parameters. The resulting points are irregularly distributed in this plane and carry the grey value of the corresponding image points. The transfer to the regular grid is solved by interpolation using weighted averaging of grey values of all neighbouring points within a certain radius. The weight is chosen reciprocal to the distance between the grid point and its neighbours. If no neighbours are found around a grid point, as this is the case outside the borders of the image, a background value is assigned to this pixel. Examples of the rectification are shown in figures 6 and 8.

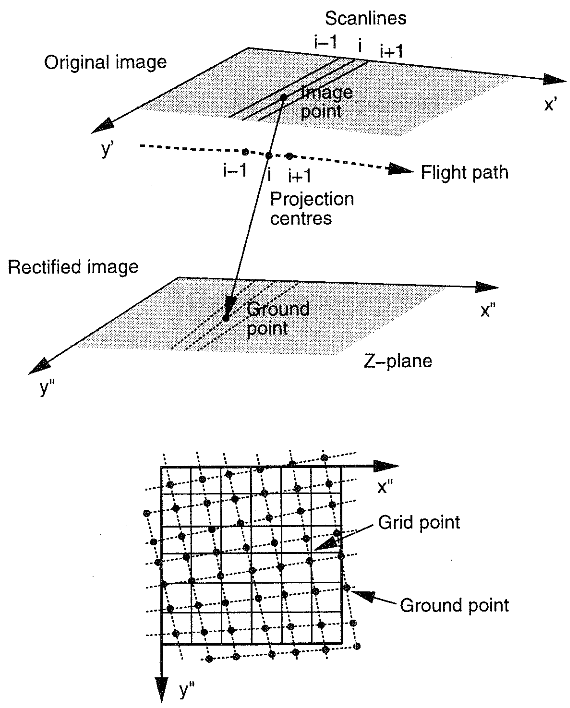

Figure 9: Image rectification

4.3 Multispectral Analysis

Our primary interest in extracting information from the multispectral component of DPA is currently focused on the field of topographic and thematic mapping. Tasks like the extraction of roads or the detection and reconstruction of buildings or other man-made objects are research topics of digital photogrammetry for which automatic procedures are under development. First successful experiments have been presented by Haala and Hahn (1995) and Weidner and Förstner (1995). Major information source used in that work is the digital terrain model and the aerial stereo image pair. Critical steps of those procedures are the detection of objects and the discrimination of different object classes. With respect to this critical steps we expect that the multispectral data of DPA will be a very useful source. This assessment is supported by the work of Shettigara et al. (1995). They developed a procedure for extraction of man-made objects from multispectral aerial images.

For the multispectral investigation an area is selected in which vegetation, buildings, streets and other objects are imaged. The near infrared channel of this area is depicted in figure 10.

For the classification we used the isodata algorithm. This is a well established iterative optimization clustering procedure. It is based upon estimating some reasonable asignment of the pixel vectors into candidate clusters and then moving them from one cluster to another in such a way that the sum of squared error over all pixels to the corresponding cluster mean is reduced. To get a reasonable assignment for candidate clusters supervised classification with an upper limit for the number of classes is used. For example, we have chosen a maximum of 30 classes.

The result of the Maximum Likelihood classification together with the labeling of the classes is shown in figure 11. This first result with the very coarse classes of vegetation, roofs (buildings), roads or other sealed areas and shadows of buildings and trees reflect some of the information covered by a topographic map. For comparison the corresponding part of the map is plotted in figure 12.

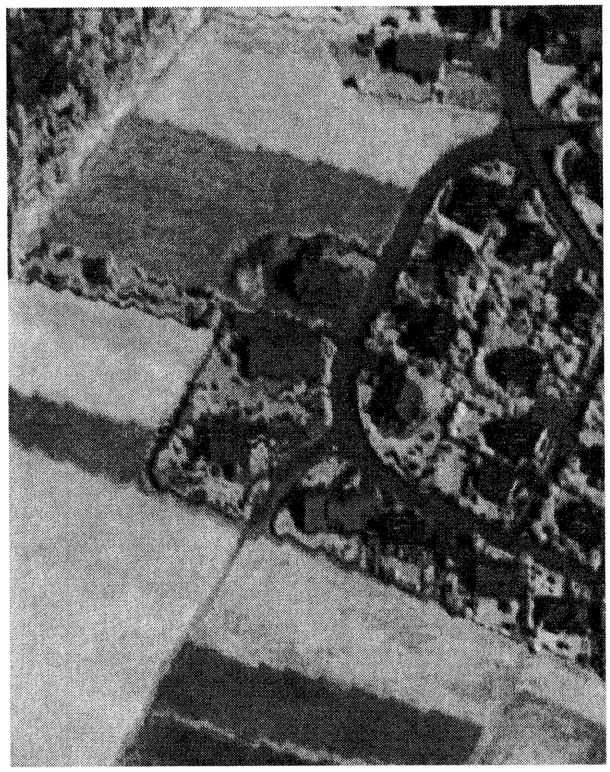
Figure 10: Near infrared channel

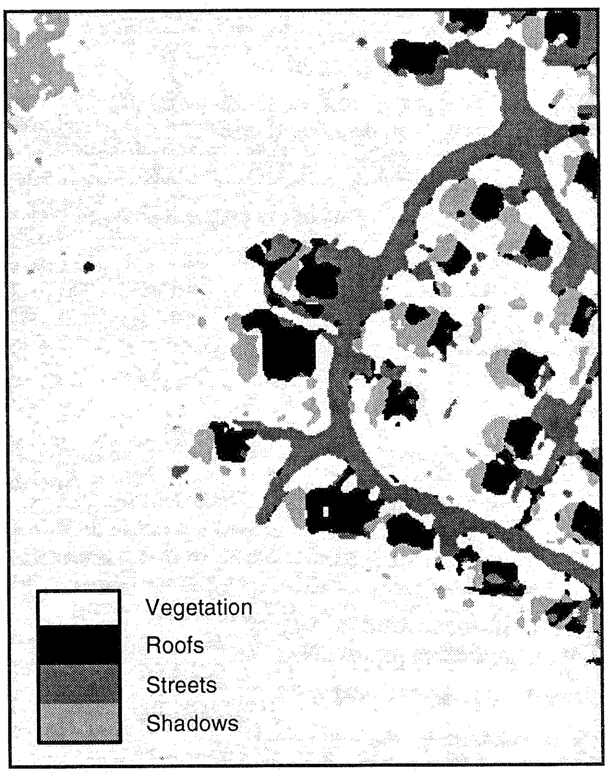

Figure 11: Multispectral classification

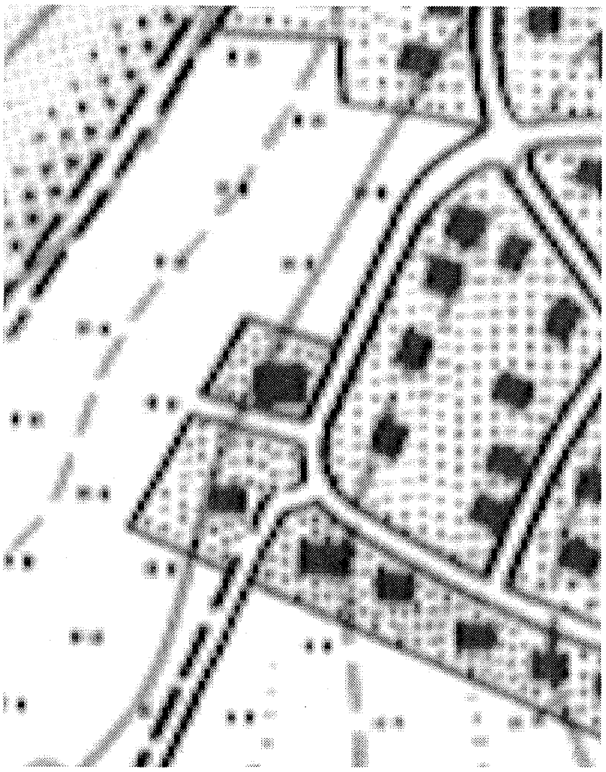

Figure 12: Topographic map 1:25000

This first classification result can be taken as a useful hint for the detection and extraction processes mentioned above. In the class "roofs" all buildings of the scene are present thus a precise detection of this regions is strongly supported by the multispectral data. The same holds for the road network. Also useful is the information about shadow regions because in this areas it is often difficult to distinguish between the contours of buildings and the contours of the adjacent shadow regions.

That automatic procedures for DTM reconstruction may also profit from the multispectral data show the following considerations. If, for example, water regions are present in the scene they generally have to be marked to avoid matching in these regions. If a part of the scene is covered by forest then matching ends up with the surface of the canopy. But if now those informations on the regions in the scene are extracted by multispectral analysis this knowledge can be used to guide the DTM modules with an object specific treatment within the recovery process.

5. OUTLOCK

For the evaluation of the DPA sensor system an extensive test flight experiment has been carried out in 1995. Investigations on the GPS-INS integration for georeferencing the image data and on rectifying the images are presented in this paper. Other work mainly with the 3D point determination from the three-line imagery are left for the future. With respect to 3D reconstruction first results from a previous experiment have been reported in Kaltenecker et al. (1994).

In the work carried out next we concentrate on

- the automatic measurement of the signalized points in the DPA images as well as in the simultaneously taken aerial images
- automatic point transfer in the stereo data of DPA but also between DPA and aerial images which allows to check the quality of DPA 3D reconstruction with natural points.
- a further investigation of the multispectral classification which can be expected to improve if rectified panchromatic and multispectral channels are used simultaneously together with more advanced classification procedures.

ACKNOWLEDGEMENT

The DPA project is funded by the German Federal Office for Military Technology and Procurement (BWB) in Koblenz.

REFERENCES

Eckardt, A. [1995]: The Performance of the new Wide Angle Airborne Camera (WAAC), ISPRS Intercommission Workshop "From Pixel to Sequences", Zurich, March 22–24 1995, IAPRS, Vol. 30, Part 5W1, pp. 26–29.

Fritsch, D., Hahn, M., Schneider, F. [1995]: Automatic DTM Generation with MOMS-02/D2 Mode 1 Data, Remote Sensing and Reconstruction for Three-Dimensional Objects and Scenes, pp. 20-27, SPIE Vol. 2572, San Diego, California, July 1995.

Gibson, J.R., [1994]: Photogrammetric Calibration of a Digital Electro-Optical Stereo Imaging System, Geomatica, Vol. 48, no. 2, pp. 95–109.

Haala, N., Hahn, M. [1995]: Data Fusion for the Detection and Reconstruction of Buildings, Automatic Extraction of Man-Made Objects from Aerial and Space Images, Gruen, A./Kuebler, O./Agouris, P. (Eds.), pp. 211–220, Birkhäuser Verlag, Basel, 1995.

Kaltenecker, A., Müller, F., Hofmann, O. [1994]: Digital Photogrammetric Assembly (DPA) — an Airborne Stereo and Multispectral Imaging and Evaluation System, 1st International Airborne Remote Sensing Conference and Exhibition, Strasbourg, France, 11–15 September, 1994.

Kramer, H.J. [1994]: Observation of the Earth and its Environment, 2nd Ed., Springer Verlag.

Murai, S., Matsumoto, Y., Li, X. [1995]: Stereoscopic Imagery with an Airborne 3-Line Scanner (TLS), ISPRS Intercommission Workshop "From Pixel to Sequences", Zurich, March 22–24 1995, IAPRS, Vol. 30, Part 5W1, pp. 20–25.

Schwarz, K.P. [1995]: Integrated Airborne Navigation Systems for Photogrammetry, Photogrammetric Week '95, pp. 139–153, D. Fritsch/D. Hobbie (Eds.), Wichmann Verlag, 1995.

Shettigara, V., Kempinger, S. and Aitchison, R. [1995]: Semi-Automatic Detection and Extraction of Man-Made Objects in Multispectral Aerial and Satellite Images, Automatic Extraction of Man-Made Objects from Aerial and Space Images, Gruen, A./Kuebler, O./Agouris, P. (Eds.), Birkhäuser Verlag, Basel, 1995.

Weidner, U., Förstner, W., [1995]: Towards Automatic Building Reconstruction from High Resolution Digital Elevation Models, ISPRS Journal, Vol. 50, no. 4, pp. 38–49.