
TEST RESULTS OBTAINED WITH THE LH SYSTEMS ADS40 AIRBORNE DIGITAL SENSOR

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Working Group I/3

KEY WORDS: Camera, CCD, Sensors, Radiometric Qualities, Photogrammetry, Remote Sensing, Data Processing.

ABSTRACT

LH Systems, in co-operation with the German Aerospace Centre, has developed an airborne three-line digital imaging sensor, the ADS40. This sensor will provide imagery complementary to satellite images and aerial photos.

The engineering model (EM) of the ADS40 has been successfully flown since late 1998. This paper describes the airborne experiments with the EM and its results. These experiments are restricted to the overall systems functionality only. The paper focuses on the principal test procedure and a few products derived from ADS image data. The emphasis is placed on general problems of developing new sensor systems and proves the necessity of detailed tests of all hardware subsystems and software parts at a very early stage of camera development.

Additionally, the improved model with approximately 20,000 pixels per line is introduced. This prototype model (PM) was first flown in January 2000. Staggered arrays allow an improvement of the geometrical resolution, but require special retrieval algorithms.

1 INTRODUCTION

LH Systems, in co-operation with the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt – DLR), has developed an airborne three-line digital imaging sensor, the ADS40. Because of the linear sensor structure, the second dimension of the image is generated by the aircraft movement and is influenced by attitude disturbances. To overcome this problem and to correct this effect, exact attitude and position measurements are necessary for each image scan line.

The main purpose of this paper is to show the importance of detailed tests at a very early stage of camera development. The paper is focused on test flights with the ADS engineering model (Eckardt and Sandau, 1999). The planning and carrying out of the test flights, the equipment used and essential data processing steps are introduced. We give a few examples of using test results in order to identify problems in hardware and software. These results were used in the development of the later camera models, PM (prototype model) and SM (series model). The quality of important system parameters was verified, sources of errors identified, and know-how acquired about dealing with the entire system.

1.1 Aims of test flights

The most important goal of the test flights was to prove the functionality of the entire ADS40 system including the camera, the platform and the inertial measurement unit (IMU). A check of the system under real flight conditions was necessary. The main objectives of the test flights were defined as:

- test of the camera system,
- verification of the chosen hardware parameters,
- test of the synchronization between image and attitude data, and
- test of the pre-processing facilities and retrieval algorithms.

This paper has the following structure. Firstly, both ADS40 test camera systems (EM and PM) are briefly introduced. Then the flight experiments are described and the data pre-processing steps explained. The main part deals with the results obtained from the ADS40 test flights and the conclusions drawn for the next steps in camera development.

2 ADS TEST CAMERAS

The ADS40 cameras are CCD line scanners using the push-broom principle. Although the application of CCD matrices would have a number of advantages over linear arrays with respect to the data processing, CCD lines are the only sensors providing the ground resolution combined with a swath width fulfilling the specifications given by photogrammetry at present and in the near future.

The along-track stereo capability of the ADS40 is achieved by using three lines with different viewing directions (forward, backward, nadir). The development of the ADS40 engineering model (EM) was finished in the middle of 1998 and was based on DLR's WAAC (Sandau and Eckardt, 1996). The prototype model (PM) followed one year later. Both cameras were built for a stepwise ADS40 development and in order to provide tests continuously. Figure 1 shows both ADS40 test models, the EM and PM respectively. Table 1 gives a short overview about some important camera parameters.

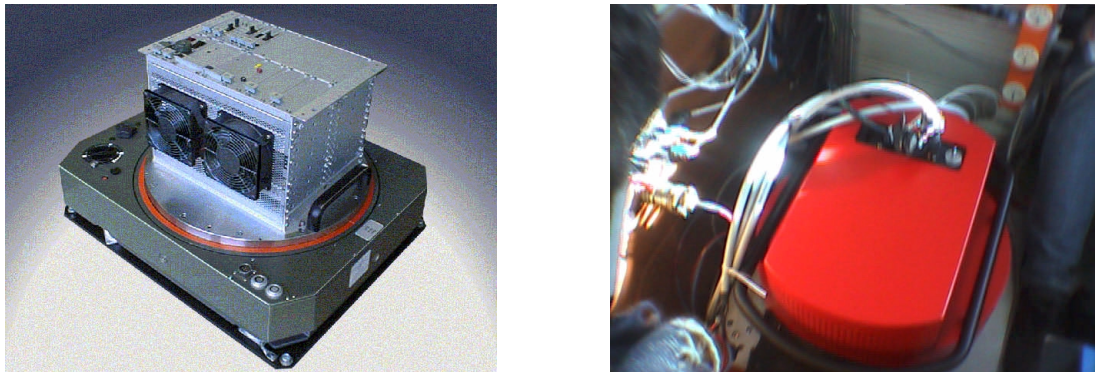


Figure 1. ADS40 engineering model (left) and production model (right)

Camera parameter	EM	PM
Detector	3 CCD-lines (12,000 pixels)	3 CCD-lines (24,000 pixels)
Focal length	80 mm	47.3 mm
Field of view	52°	79°
Stereo angles: forward / nadir, backward / nadir	17° 25°	21° 34°
Radiometric dynamics / accuracy	12 bit / 8 bit	12 bit / 8 bit
Flight height / GSD / swath width	3,000 m / 0.24 m / 2,900 m	3,000 m / 0.20 m / 4,900 m
Mass memory	3 x 9 GByte	6 x 50 GByte

Table 1. Parameters of the ADS40 test models

3 FLIGHT EXPERIMENTS

The first test flights took place on 10-11 November 1998 with a Cessna chartered from the Rheinbraun company. The camera (EM) was mounted on an LH Systems PAV30 platform. The attitude measurements were made with an Applanix LR86 system of the DLR Institute for Space Sensor Technology and Planetary Exploration. Capturing the first images shortly after assembling the LH Systems and DLR camera parts was an exciting moment (figure 2). The data already showed the high potential of ADS40 concerning the geometric and radiometric resolution.

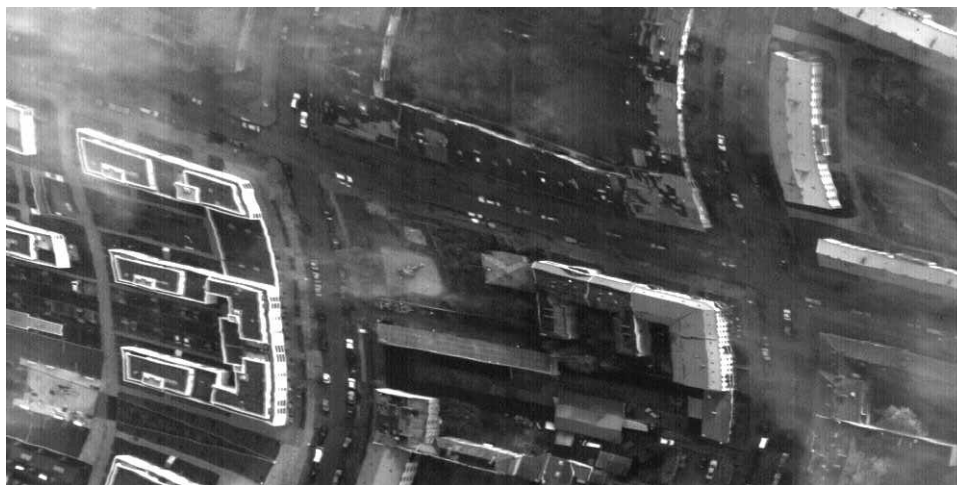


Figure 2. Part of the first image scanned by the ADS40 engineering model

3.1 Aeroplane

Later on, between April and December 1999, a number of test flights was undertaken using a Cessna T207A of the Free University of Berlin (Institute for Space Science). It allowed us short term access to an aeroplane, which was very important during the first test phases. Figure 3 shows the single-engine plane.



Figure 3. Cessna T207A of the Free University of Berlin

3.2 Platform

For the tests two different stabilised platforms were used: LH Systems' PAV11 and PAV30, which were easily mountable into the aeroplane. Both platforms were not adapted to the ADS40 test models, so an optimal damping behaviour could not be expected. But since the expected motions of the aeroplane were too strong in comparison to the instantaneous field of view (IFOV), we decided to use a non-adapted platform rather than no stabilisation at all. Additionally, shock mounts were fixed between aeroplane and platform.

3.3 Inertial measurement unit

The test flights were done using an Applanix LR86 system mounted inside the camera cover. The lever arms from the camera to the IMU and to the GPS antenna were determined. It was known that the internal LR86 sampling rate of 90 Hz was not sufficient for a full rectification of the ADS40 imagery because of its scan frequency in the range of a few hundred Hz (corresponding to a typical clock time of some milliseconds). The oscillations beyond 90 Hz should be suppressed by the stabilised platform and the shock mounts. Thus it was expected to obtain data good enough for a rough system evaluation and for localising of general problems. The attitude data were recorded during the entire flight and the synchronisation to the image data was achieved by using events triggering the camera. Reference data for the differential GPS solution were obtained from the Landesvermessungsamt Berlin.

3.4 Test area

A test area was selected in the south of Berlin covering the airport of Berlin-Schoenefeld, since this was well suited for an evaluation of geometric accuracy owing to its long straight taxiways. A new, small test field was prepared within this area for a coarse verification of the geometric accuracy of the whole system. Therefore, 15 ground control points were marked and measured. Figure 4 shows a typical arrangement of a set of tracks over the test area.

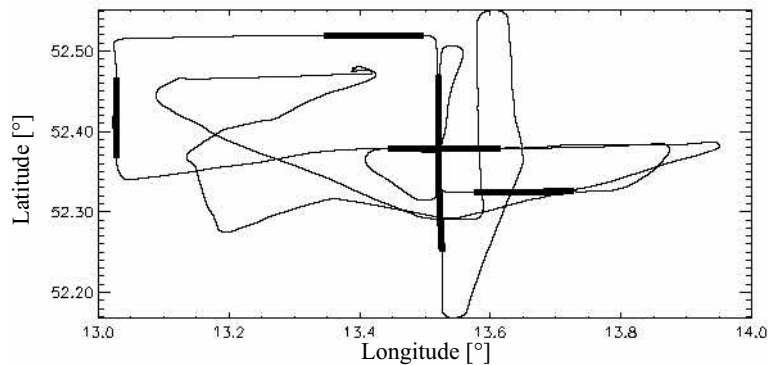


Figure 4. Typical arrangement of tracks of one test flight over Berlin

4 DATA PROCESSING

After image generation the data pre-processing has to be done. All retrieved data must be extracted from the mass memory system and converted into a usable format. This is the task of the so-called Level 0 generator.

In order to prove the overall system functionality including the camera electronics and optics, the platform and the IMU, the data processing was extended to more complex tasks. Different products were generated for coarse tests. It was not intended to obtain point accuracy usable for photogrammetric measurements.

4.1 Pre-processing of the image data

The three CCD lines of the EM, with 12,000 pixels each, generate a file with a size of about 1.5 GByte assuming a typical number of scan lines (60,000) and a radiometric resolution requiring a two-byte data format. A program running on a Windows NT computer extracts the image and housekeeping data. The commercial ADS40 version will use a special library of SO CET SET® handling image files exceeding 2GByte. The time consuming Level 0 generation must be able to create raw image data in an acceptable time frame. Since this procedure is independent of the ADS40 hardware itself, it is the first part in which one is able to detect systematic electronic errors.

4.2 Processing of the attitude data

The processing of the attitude data was done using the Applanix software PosProc. It determines 50 and 200 Hz solutions including the real-time data and the reference data by applying certain signal processing algorithms, e.g. Kalman filtering. The position data were transformed to a local coordinate system (Soldner) or to UTM. Using the events triggering the camera, the image and attitude data were synchronised. This results in an attitude file containing the parameters for the exterior orientation for each track.

5 INVESTIGATIONS AND RESULTS

The following camera and total system parameters were of special interest during the test flights in order to check the functionality and to evaluate the general capabilities of ADS40:

- radiometry of the ADS40,
- evaluation of the platforms,
- accuracy of the attitude parameters.

5.1 Radiometry

One of the main advantages of digital sensor systems over film-based cameras is the much higher radiometric dynamics, equivalent to a greater range of grey values within an image. This has a significant impact on the subsequent data process-

ing (e.g. matching). The dynamic range is described by the radiometric resolution and is limited by different noise sources. Both of these parameters, radiometric dynamics and noise, were main points of our investigations.

Figure 5 shows the histogram of a small part of a test image. Grey values between 140 and 2750 were detected. In order to differentiate these, 12 bits are necessary.

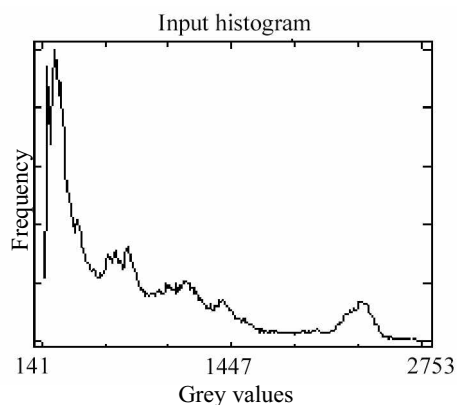


Figure 5. Histogram of the EM

Figure 6 gives an impression of having 12 bit data instead of 8 bit data at one's disposal. Depicting either the first 8 or the last 8 bits within the original 12-bit grey level range results in two different images. The first shows the bright parts, but no structure in the dark parts is detectable. The second image inverts the situation: in the dark parts we can see details, the bright pixels look saturated. But again, both images result from the same 12-bit image.

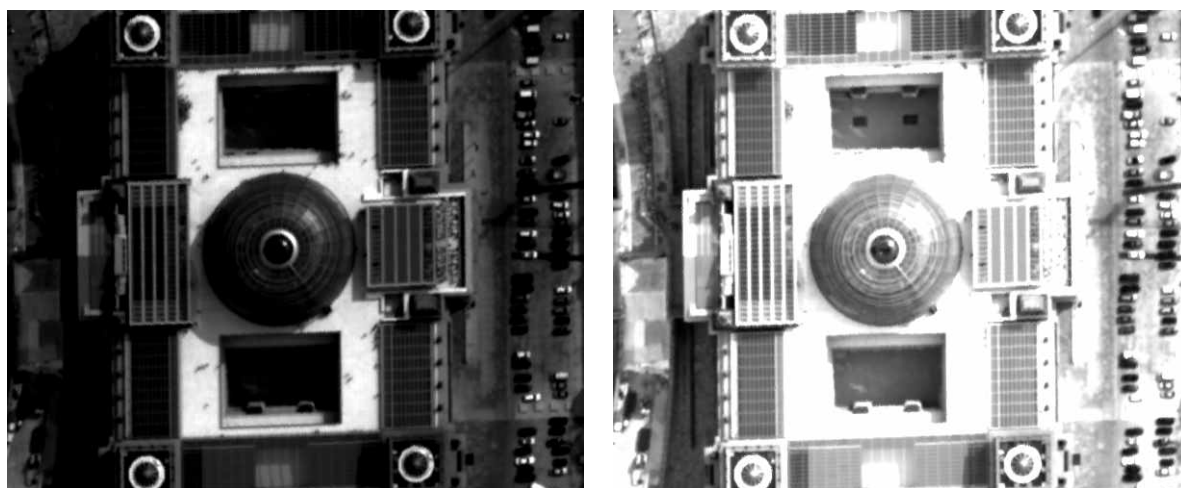


Figure 6. Radiometric zoom, depicting grey values of the first (left) and the last (right) 8 bits within the original 12 bit grey level range

A noise analysis must be performed to ensure the estimated radiometric resolution. In general, dynamic and static noise can be differentiated. A number of homogeneous targets in certain test images was selected in order to investigate the dynamic, time dependent noise. Figure 7 shows the result. A nearly Gaussian distribution can be seen. The standard deviation is about 2 grey values. The limiting dynamic noise source in any case is the photon noise.

The pixel response non-uniformity (PRNU) describes the pixel-dependent (and time independent) digital output of a CCD sensor for a constant amount of input radiance. Limb shading caused by the optical parts can be described in the same way. This effect is important for real-time compression algorithms and must be corrected before data compression, because it influences the quality of decompressed image data drastically (Schlotzhauer *et al.*, 1994). The ADS40 system compensates the PRNU in real-time by using look-up tables for correction values. Figure 7 also illustrates the PRNU effects. The mean grey value of the same pixel of different scan lines in a homogenous target was calculated. These means are printed for a subset of the CCD line and describe remaining PRNU effects (rms smaller than 1 grey level).

With these tests we could prove the capability of the ADS40 to generate images with a radiometric resolution of 12 bits.

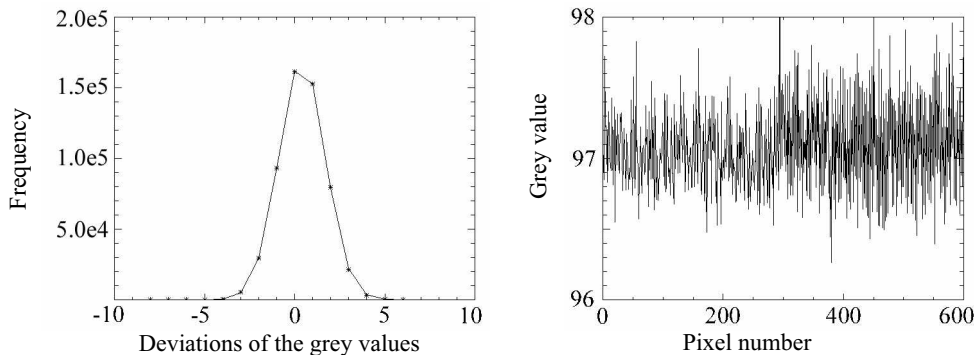


Figure 7. Standard deviation of grey values (left) and PRNU effects (right) determined using homogenous targets

5.2 Evaluation of the platforms

An adaptation of the platform control on account of the camera allows an optimal damping of the system. As mentioned above, no adaptation was done for the EM.

In all EM raw images an oscillation can be observed (figure 9). Even if these motions are recorded correctly by the IMU, the image quality decreases because of the necessary resampling process. The amplitude of this oscillation is about 1-2 pixels in image space and the period is about 15 scan lines, which is related to a time of about 50 ms. This oscillation results from the 20 Hz revolution frequency of the Cessna engine. The platforms used were not able to suppress these vibrations. Figure 8 (left) shows the power spectrum of the processed IMU data. The 20 Hz peak can be seen clearly.

In order to validate these results the EM and the Applanix system were put on a shaker together. Its stimulating oscillation was swept from 1 Hz to 100 Hz and the system response was recorded by the IMU. Figure 8 (right) shows a part of the test data. For vibrations between 10 and 15 Hz the platform was too inert for a damping of the EM. Damping worked for stimulating oscillations beyond 15 Hz. The most interesting detail in this figure is the resonance frequency at 20 Hz, which confirms the evaluation of the image and attitude flight data.

In order to minimise the oscillation effects even for test flights in future it was decided to apply additional weights to the camera until the new, adapted platform is available.

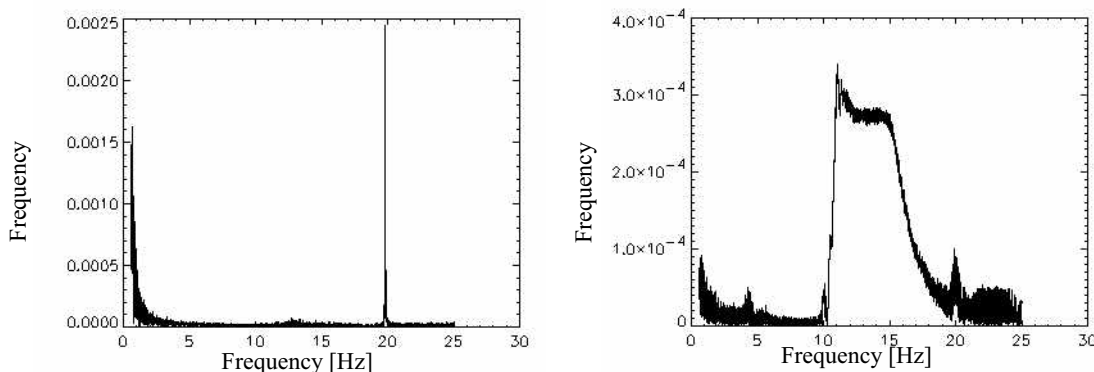


Figure 8. Power spectrum of the oscillations of the ADS40 EM on the non-adapted PAV11 during the flight (left) and on the shaker (right)

5.3 Accuracy of the attitude parameters

To evaluate the quality of the attitude data we performed a rectification of image data to a reference plane (correction of the flight motions) and the generation of a coarse digital terrain model (DTM). The most important feature, the accuracy of point reconstruction, will be discussed at the Congress.

After processing of the IMU data, a simple way to verify the alignment between image scan lines and an appropriate attitude data set is to project all pixels of the raw image to a reference plane (rectification, figure 9). The visual impression of a rectified image is the first, essential indicator of the quality of the attitude data. This method helped us to detect different synchronisation problems, e.g. a temporary 8-line shift between attitude and image data.

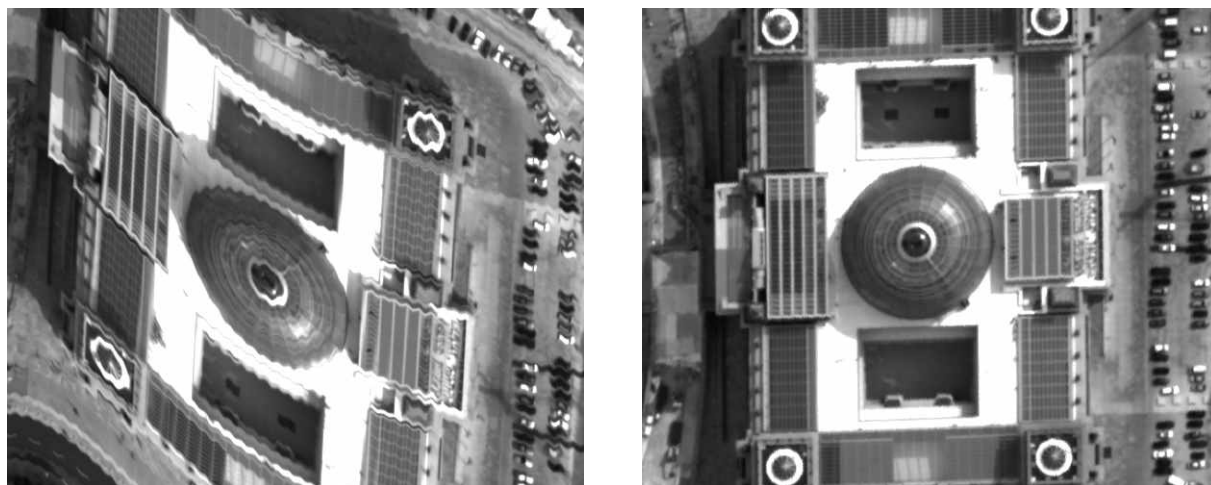


Figure 9. Raw and rectified image

Although we restricted our data processing to general tasks and exact photogrammetric restitution was not our goal at this stage, we proved the stereo capability of the EM. With a small number of control points and simple algorithms we already achieved an error (rms) of about one pixel in the x - and y -directions and about three pixels in the z -direction, taking into account additional built-in offsets for roll, pitch, and yaw. With the help of these improved position and attitude data we generated digital elevation models. This task is very interesting, because it is the last element in a long, complex chain, starting with the optics and electronics, including aeroplane and platform, and ending with data processing. Some errors can only be detected at this final stage. Only when all elements of this chain work together successfully can high quality photogrammetric products be obtained.

Figure 10 shows a part of a terrain model calculated with a tool developed at DLR for automatic DTM generation from line scanner imagery (Börner, 1999). Two independent DTMs were built for two different tracks (one south-north, another north-south) flown over the same target area within one hour.

The first additional criterion for successful processing is the correlation between the stereo images. The matching algorithm worked very well (about 90% of all candidates were matched) and encountered no problems handling the 12-bit data.

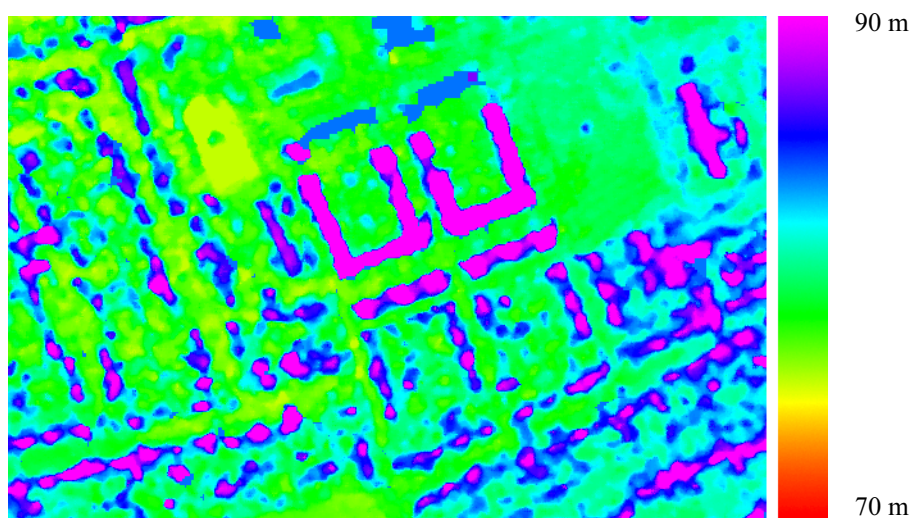


Figure 10. DTM generated from ADS40 image data. Buildings can be recognized easily. The colors indicate different heights.

Superimposing both DTMs showed deviations smaller than 1.5 pixels (rms). This error includes all error sources, e.g. attitude data error, matching error and reconstruction error.

6 CONCLUSIONS AND OUTLOOK

This paper describes the planning, performance and results of the very first flights of the ADS40 test models. Our main goal was to illustrate the importance of detailed tests of the complete camera system under real conditions. These tests must complement laboratory tests and the development of retrieval algorithms. This is the only way to detect error sources at an early stage and can confine the development risks drastically.

With the help of the test flights, we were able to identify a number of sources of hardware errors and could acquire considerable know-how dealing with the camera system. We were able to prove the capability of the ADS40 to generate images with a radiometric resolution of 12 bits with low noise. Although exact photogrammetric restitution was not our goal, we were able to verify the quality of the position and attitude data for coarse data products.

ACKNOWLEDGMENTS

We would like to thank all colleagues and supporters of our work, especially

- Mr. Lindemann for his pilot activities,
- Prof. Fischer for his friendly support of the flight experiments,
- Michael Nitz, Michael Grainer-Bär, Michael Neidhardt and Mathias Uhlig for carrying out the experiments,
- Michael Herrmann and Adrian Schischmanow for their test field and GPS activities.

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