APPLICATIONS OF VERY HIGH RESOLUTION DIGITAL AIRBORNE SCANNER DATA

Matthias Moeller
University Vechta
Institute for Environmental Science
matthias.moeller@uni-vechta.de
http://www.iuw.uni-vechta.de

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ABSTRACT

This paper deals with a number of new applications for digital airborne scanner data of very high precision. The process of preparation the image data for public access is described first. In the second part of the paper a new approach for the generating of a digital surface model (DEM) is specified. In the last part the extraction of elevation of building is presented. The results for validation and accuracy assessment for the calculated height data are presented. Some errors that could appear due to the process are discussed at the end of this paper.

1. INTRODUCTION

Digital images have become more and more popular for scientific research, public information and for fast growing markets of 3D modeling and virtual reality (Fritsch, 1999). With the launch of Ikonos II in September 1999 the ground resolution of digital images from space has improved to one meter, which means that the age of very high resolution (VHR) images has been started (Neer, 1999). Using digital airborne scanner data for earth monitoring, the era of extremely high resolution imagery (EHR) with ground resolutions of 0.5m–0.1m has began. An EHR with an excellent geometrical precision and 4 multispectral bands provides much more information than common aerial images can do. This is an enormous potential for both public use and scientific research.

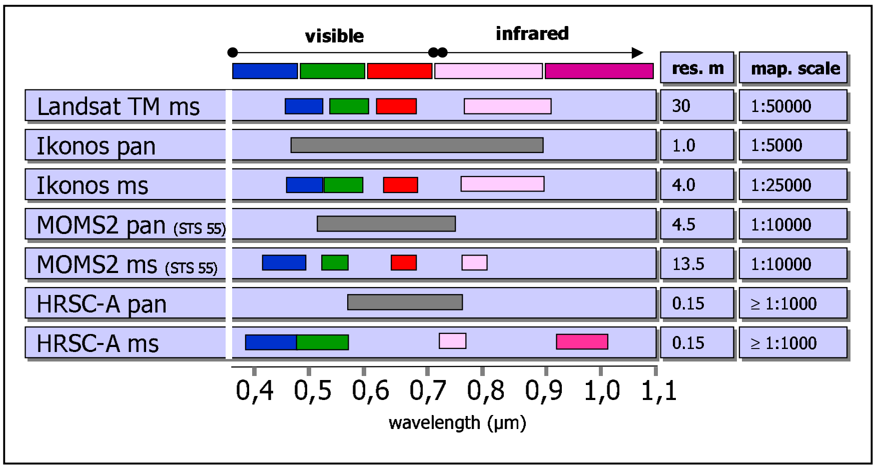
The City of Osnabrueck's long tradition in aerial imaging goes back to the year 1935. Since this year aerial photographs of the city have been taken for every 3-5 years. In 1985 the first color images were taken. Nowadays the process of spatial planning becomes more and more digital in a computer assisted environment. The cadastral data will be updated only in digital form from 1998 on and it will be delivered to customers preferably as a digital file. Having this in mind, a digital base of photographic data should be very useful for the planning process in a public administration. For the year 1999 a new flight campaign was planned by the municipality. The intention was to use modern digital technology for acquiring the aerial image data. In April 1999 the total urban area of the City of Osnabrueck was covered by a digital multispectral stereo airborne scanner mission. The total area is about 120km² with an overlap of ca. 60%.

2. The Digital Scanner HRSC-A

The High Resolution Stereo Camera - Airborne (HRSC-A) was developed for the MARS 96 Mission by the German Aerospace Center (DLR), Institute of Space Sensor Technology and Planetary Exploration (Scholten, 1996). Its mission goal was to scan the surface of the planet mars but due to a launch failure the camera did not reach its destination. An identical one was later mounted on an aircraft (Cessna 208) and flown by the DLR. The HRSC-A is a four band multispectral (ms) stereo line scanner, the electromagnetic sensitive is controlled by filters. The acquired spectrum ranges from the blue, green to the near IR (see fig. 1), the radiometric resolution is 10 bit, but will be reduced to 8 bit due to processing. Unfortunately the red band, which is important for the distinction of vegetation and non-vegetation, is not acquired by HRSC. The panchromatic band begins in the far green and ends in the IR. Due to the missing red band it is difficult to create 'true color like' image similar to conventional aerial imagery.

Five additional bands in angles of 18.9°, 15.9° and 0° forward, after and vertical in flight direction, provide photogrammetric, stereoscopic and nadir information. Two of them are necessary to calculate photogrammetric compensation (15.9°). Two are needed to calculate the digital elevation model (DEM) from the inflight stereoscopy (18.9°), at least one band provides a vertical nadir view. One scanline consists of 5184 pixels, each pixel is acquired by a CCD chip of 7µm in size (for more technical details see http://solarsystem.dlr.de/FE/html/techdata/hrsca.shtml).

Figure 1. Spectral properties, spatial resolution and mapping scale for common remote sensing systems



The scanrate for every line is 450hz. To keep the motion of the camera in a small range the instrument is installed on a Carl Zeiss T-AS stabilized platform. The rate of signals from the differential global positioning system (DGPS) and the inertial measurement unit (IMU) provided by an Applanix positioning and orientation system is 200hz. All the data (image and positioning) is stored on tape by a high speed recorder. By knowing the cameras optical orientation, the speed of the aircraft, the x- y- and z-flight-position and the angles of the aircraft rotating around its three axis, it is possible to calculate the exact location on the earth surface for every second scanline. Other lines of pixels have to be interpolated. The resulting images are of a very high geometric accuracy, the error is ±0.15m x and y and ±0.20m in z corresponding to a flight altitude of 3000m (Wewel et al., 1998, Jacobsen, 2000). A ground resolution of 0.15m was found sufficient for the monitoring of urban areas. That results in a flight height of 3000m over ground and one flight strip covers a swath width of 777m.

3. FLIGHT CAMPAIGN

Related to the geographical location of the urban area of Osnabrueck with its extends of 17km in E-W and 13km in N-S 18 strips were flown each from E to W. This is important because the sun illumination varies from SE in the morning to SW in the afternoon when the campaign was finished. The campaign took place early in the year, a requirement of the cadastral and surveying office. Some small portions of vegetation, especially on ground, were desired, trees and bushes should have some very small leaves. These conditions would provide a good ground view but it should also be possible to discriminate several parts of vegetation using multispectral indices. A disadvantage is the rather flat sun angle over the horizon in this time of the year which resulted in long shadows. In some cases, when large buildings are along a small road, the road is totally covered by shadow. The campaign took place on April, 2nd 1999. Unfortunately the developing vegetation appears not in a uniform pattern as it does in summer. The warmer temperature in cities, urban heat layer, is probably responsible for the phenomenon that vegetation development increases more and more toward the center of the city (Oke, 1987). During the images acquisition expansive ground truth took place, where 152 ground control points were mapped with their specific vegetation phenotype.

4. DATA PROCESSING AND PREPARATION FOR PUBLIC ACCESS

The image and geocoding data were processed by the DLR and delivered band by band. The IUW used these data to build up a user-friendly interface that could be handled by everybody even people with a lack of knowledge in computer usage. We decided to prepare the data for a world wide web (WWW) interface based on the hypertext markup language (html) standard 4.0 and javascript. The advantages of this concept are the compatibility to all platforms and operating systems (OS) and the long-term development of the internet standard html (cf. Evans, 1994). The administration of Osnabrueck is already networked with a local area network (LAN), some of the staff members have access to the WWW.

As mentioned before the image data should be the base for digital urban planning processes. It was essentially that the images were stored as a fundamental part of the urban environmental information system (UIS) which is still in the stage of development. Because of the large data volume for the whole city area, we developed a procedure to devide the data in smaller tiles. The dataset was gridded into subsets of 1km² by the DLR in accordance with the scheme for standard cadastral maps (fig. 2a) (a detailed description of processing is provided by Renouard and Lehmann, 1999). The ground pixel resolution was decreased by 1cm to 0.16m to get an even number of 6250*6250 pixels per image file. This results in 206 seamless tiles (fig. 2b), each georeferenced and orthocorrected with an exact lower right (lr) corner in geographic coordinates. The convention for naming follows the cadastral scheme too.

As a standard format for the storage of the original data which can be used by a common Geographical Information System (GIS) the Geotiff-format was chosen. It provides the geographical coordinates of the reference system in the image header. The subsets, each of them 120MB in size, were compressed to ca. 30% using a zipper.

The panchromatic band, the two IR bands and the DSM data were packed with the zipper too and stored on the UIS server. The most frequently loaded products would be the true color images. To provide short download times the pixel sizes were resampled to 0.32m and 1.28m respectively. The data format was changed to jpg. This leads to a loss of spatial and spectral information but speeds up the download times. The loss in quality is neglectable for a normal user who already has worked with analogue imagery. For the use of a jpg-file in a GIS one has to write a simple world-header text-file, that can be created by the naming convention.

Figure 2a. Data Processing and gridding schema

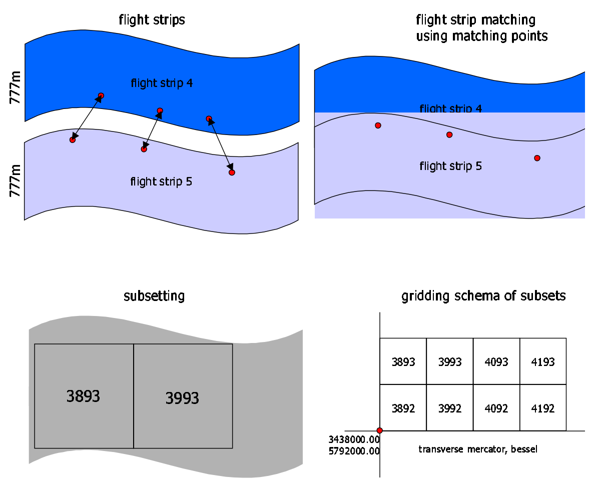


Figure 2b. City boundary for Osnabrueck and tiling scheme

Subsequently the bands of the visible spectrum (blue, green and pan) were stacked together to a *'pseudo true color'* image. The histograms –especially of the pan band- have to be modified, to get a image that looks like a true color aerial image. However, due to the missing red information, some portions of healthy vegetation still appear in light red tone.

The interface itself is programmed by using a hierarchical layer system of underlying sensitive maps. Beginning with the whole city one has to click into the district, each of them consists of four subsets. In the next step the desired subset is chosen and appears. The user can access a zip file which can be downloaded to disk or a jpg file that appears in the browser window. It can than be saved and downloaded too. The tremendous number of visits per day of the UIS server's image gallery allows the conclusion that the digital imagery is very often used and well accepted by the city staff.

5. FEATURE EXTRACTION

The digital aerial scanner images offer a lot of possibilities for automated feature extraction when compared to analogue aerial images. Due to the better spatial and radiometric resolution and an unique histogram for all images those classification algorithms known from the image segmentation of satellite imagery should work well with these data. The digital surface model (DSM) offers another decision support for the segmentation of the data.

5.1. MASKING BUILDINGS

For the simulation of spatial and temporal distribution patterns of emission (pollution, noise, air, telecommunication etc.) in an urban environment, a validated normalized 3D model for all buildings is essential. A detailed reconstruction of the building is -in most cases- not necessary (therefore see Brenner and Haala, 1999). Only the maximum height above ground and the dimensions in x and y of each buildings are needed as input data for the simulation models in the GIS or the respective models. The common way to extract height data for a DEM and for buildings is the photogrammetric restitution of aerial images. This process is usually very time consuming. In urban areas height values for buildings can be assessed very easily from aerial images, the ground surface (eg. streets) often cannot be measured because of shadow from large buildings. The spectral information in these shadowed areas are very low in scanned aerial images, this is especially the case for color-infrared images.

The HRSC-A provides reliable height data in shadowed areas because of its high radiometric resolution and its relatively wide absorbed spectrum ranging from 0.585-0.765µm. The DSM is processed by the DLR and delivered as a 16bit integer grid where the height value is expressed in cm. The ground pixel size is 0.5m for the original DSM and represents a good compromise between spatial resolution in an urban area, data size and data handling.

We used the raw HRSC-A DSM data for the interpolation of a DEM and for the extraction of building heights. As a priori information the automated cadastral map (ALK), which is available only in digital form, was used too. It provides information about the ownership and the state of use for all properties and is the most precise map data available in Germany. The object class 'building' (divided into private, public, trade and industry) was extracted from the ALK and the DSM was masked with this subset. The resulting image contains only the heights for every building above sealevel. To keep the data in a size that could be handled, the pixel size was enlarged to 5*5m pixel resolution.

5.2. MASKING STREETS AND ARABLE LAND AND INTERPOLATING A DEM

In the next step streets and farmlands were selected from the ALK. Due to the early time in the year, the farmland is vegetated only with short crops. The DSM was masked with the streets layer and the layer of arable land to achieve the areas without buildings and trees for DEM estimation. In urban areas streets are in very short distances from each other and provide a good basis for height interpolation for areas with buildings. In regions with big distances between streets the arable farmland is used to get some additional elevation points into the calculation. One problem are objects like trees and cars along and above the streets or groups of trees in the middle of the farmlands. These objects will bring intolerable errors into the DEM. To eliminate those objects slope values were calculated for the masked streets and farmland DSM. Only those elevation pixels with a calculated slope of less than 1% are used for the linear interpolation of the DEM. The resulting DEM can be seen in fig. 5e.

5.3. CALCULATING ELEVATION FOR BUILDINGS

In the next step the layer with the buildings heights above sealevel is subtracted from the interpolated DSM achieved from the HRSC-A data. The highest point of elevation for each building is selected and the elevation value is assigned to the whole building. The resulting heights are the maximum real elevation of the building above ground. The elevation is than added as one item to the ALK. The ALK can be used for visualization in an appropriate GIS. Each building can be represented as a cube in 3D (fig. 4 and http://www.iuw.uni-vechta.de/projecte/hrsc/cubes.html).
Figure 3: The calculation method for building heights from DSM

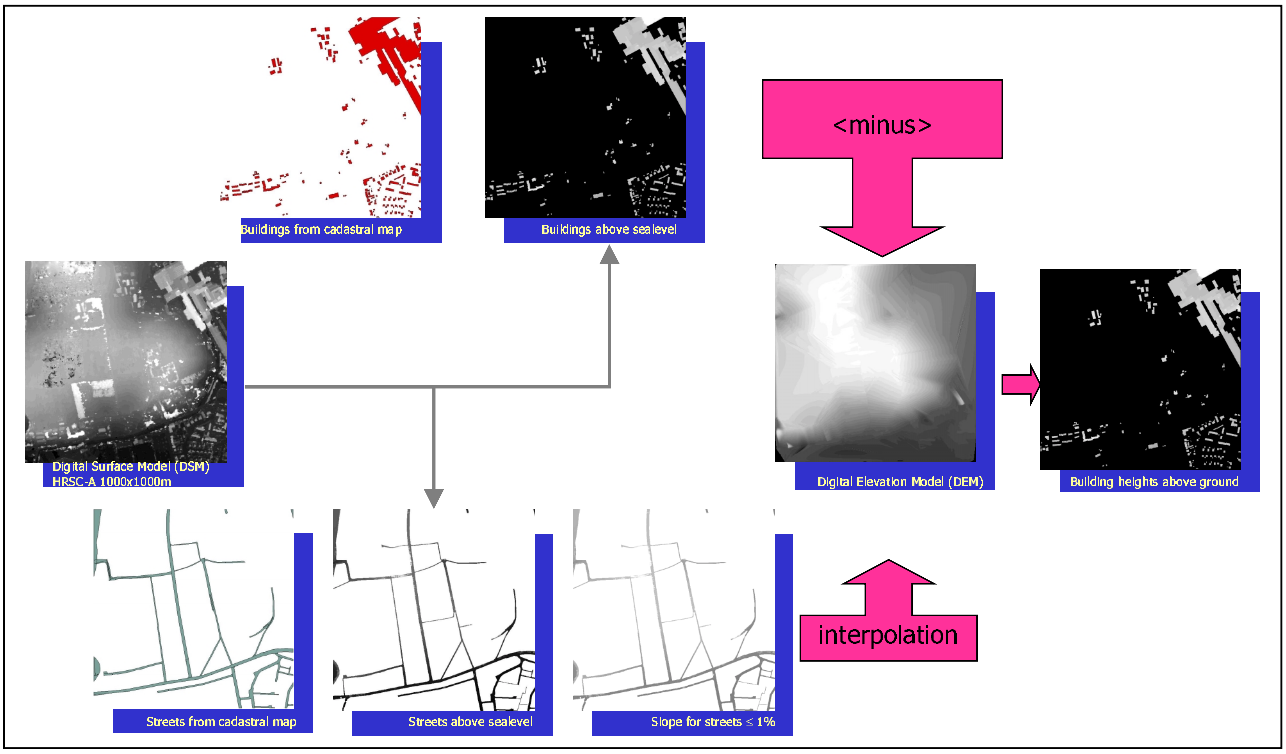
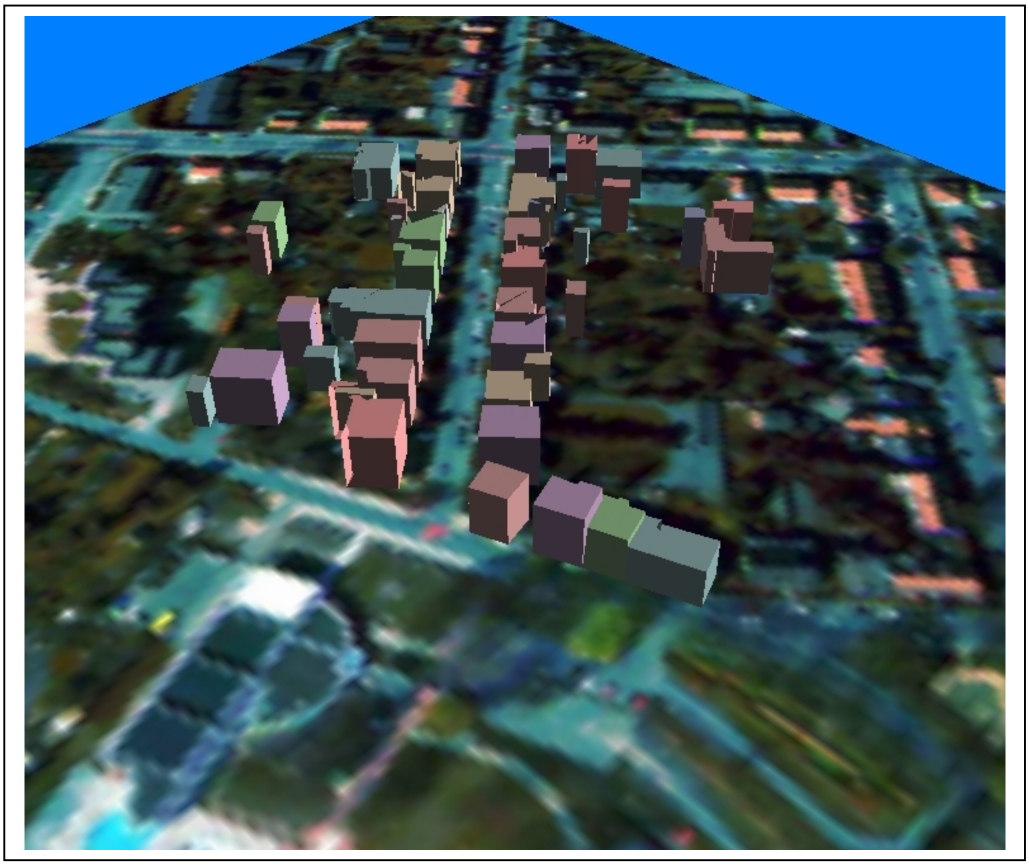


Figure 4. Buildings calculated from the HRSC-A DEM on a multispectral HRSC-A image



5.4. ACCURACY ASSESSMENT

5.4.1. ACCURACY FOR DEM

The most accurate DEM in Germany available is the DEM 5 provided from the surveying administration (LGN in Lower Saxony). The grid spacing of this DEM in x and y is 12.5m. The accuracy of the DEM 5 is ±0.5m in cities and ±1m in other areas. The elevation spots were derived mostly from aerial images by aerotriangulation, some elevation spots are digitized from 1:5000 scale maps. We compared the interpolated DEM with the LGN DEM (fig. 5 b+c). A spatial profile for accuracy testing was selected for a length of 150m in the images.

The surface was disturbed by trees along two streets (fig. 5a). After the application of our algorithm the trees are eliminated and the relief looks much more detailed than it appears in the LGN DEM. The differences between the interpolated and the official DEM can be viewed in fig. 6 in cm of differences. Further studies on the accuracy are in progress.

Figure 5a. HRSC-A DSM

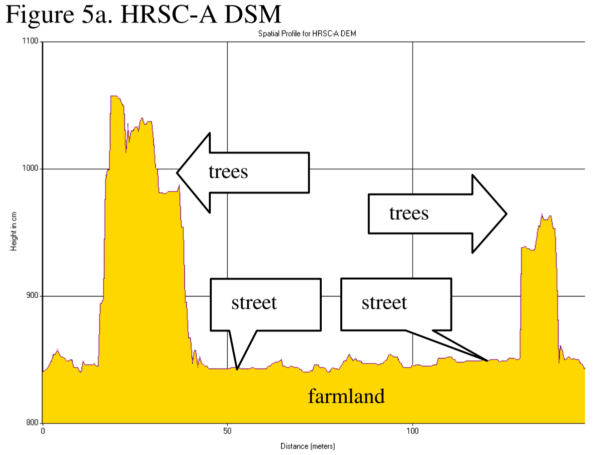


Figure 5b. LGN DEM

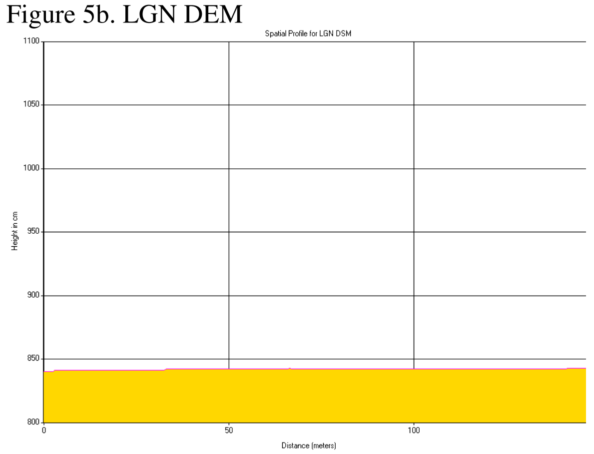


Figure 5c. Interpolated DEM from HRSC-A DSM

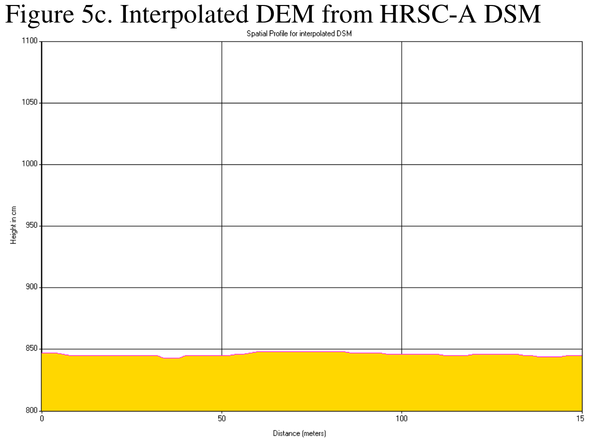
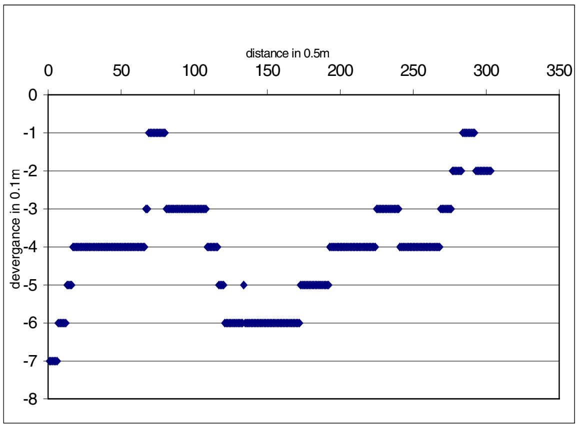


Figure 6 Divergence DEM – DEM HRSC (interp.)



5.4.2. ACCURACY FOR BUILDINGS

For checking the accuracy of heights some selected buildings were compared to its real elevation above the ground. The real elevation of each building is provided by the building control offices in a specific file. We tested buildings with a good matching (by ground control) and other ones which obviously differed. The results are of a very small error for the well matched buildings. The errors vary between 0.52-7.8% of total height (fig. 7). The correlation between real height and the calculated height from the HRSC-A DSM is about 0.9 with no constant error. Fig. 8 shows the offset from the linear regression lines for the well matched buildings.
The buildings with big differences were surveyed and inspected by ground control. Three apparent reasons which could be responsible for the divergence were found:

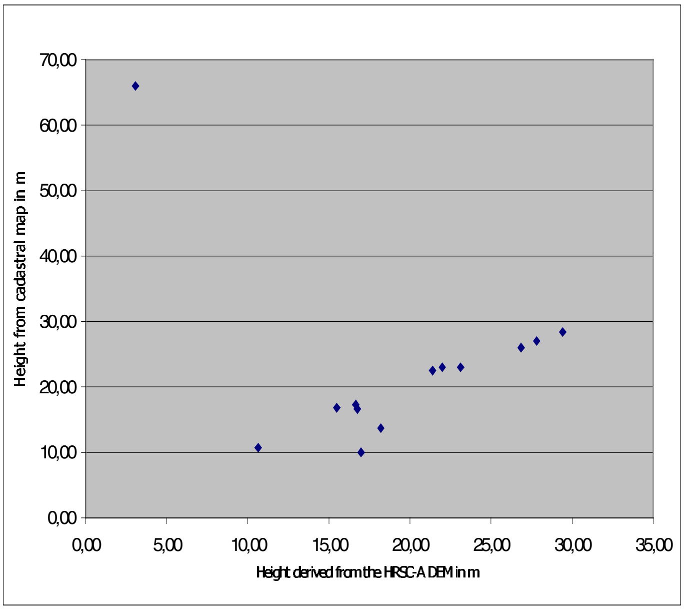
1. Some of the buildings are very small in size and they are not totally covered by the grid size of 5*5m. In such cases the point of maximum elevation may lie outside of the calculated zone.
2. The point of maximum elevation is totally shadowed and the reflected signal could not be used for the calculation of height.
3. The point of maximum elevation is very small in size and was already resampled due to the stereoscopic processing procedure.

Figure 7. True height values compared to calculated height values from DSM for urban buildings

N°	real elev.	calc. elev.	div. in %	div. without 11,12,13
1	26,00	26,86	3,31	3,31
2	23,00	21,99	4,4	4,4
3	17,30	16,66	3,7	3,7
4	16,80	15,49	7,8	7,8
5	10,70	10,64	0,56	0,56
6	16,60	16,75	0,9	0,9
7	28,40	29,42	3,52	3,52
8	27,00	27,82	3,04	3,04
9	23,00	23,12	0,52	0,52
10	22,50	21,40	4,89	4,89
11	13,70	18,20	32,85	
12	10,00	16,99	69,9	
13	66,00	3,07	95,35	
average div.			18%	
				4,4%

N° 1-10 with good matching
gray: large matching differences

Figure 8. True height values compared to calculated heights values from DSM for urban buildings



6. CONCLUSIONS AND FURTHER WORK

Digital line scanner data with an extremely high resolution offer a good potential for future tasks in urban monitoring. If they are well prepared and easy to use they will prove very popular for common users. A very good source for the production of DEM and the calculation of object heights is the provided DSM. For the first time it offers a high precision in x, y and z direction compared to analogue aerial photographs. The multispectral bands provide very detailed information about the land use. This can be used to classify the surface features to find more matching points for the DEM interpolation.

Especially in urban areas very detailed information at large scales is needed. This is true because the changes in landuse appear in short periods. We anticipate that the use of digital scanner data will become operational in the near future. The data will be used for documentation of the present conditions, but can be also used for the reconstruction of 3D models. A virtual city tour based on the image data will be created soon. This will offer the possibility to connect the results of the scientific research with the field of e-commerce.

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