

LAND USE CHANGE IN ROSTOCK, GERMANY SINCE THE REUNIFICATION – A COMBINED APPROACH WITH SATELLITE DATA AND HIGH RESOLUTION AERIAL IMAGES

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ABSTRACT:

The city of Rostock in East Germany has undergone drastic changes in the last 15 years since the reunification of Germany. To cover the spatial extent of the urban developments and the changes in land use different remote sensing sensors and image analysis techniques were used. The land use of 1989 and 1995 was determined at a 1:50.000 scale based on fused Landsat TM and SPOT satellite scenes. In 2002 a HRSC-AX flight was conducted. The land use at a scale of 1:5.000 was again visually interpreted. Sealed surfaces and the degree of sealing were determined with the help of an object oriented classification. A change analysis was performed to identify all new urban developments within these 13 years. For the mapping and monitoring of current land use changes and urban developments the digital low cost mapping system PFIFF is used to gather current information from urban “hot spots”.

1. INTRODUCTION

The city of Rostock in East Germany has undergone huge changes in the last 15 years since the reunification of Germany. Some numbers shall illustrate the change. The population of the city of Rostock declined by more than 20 %, from 252,956 in 1989 to 198,303 at the end of 2003. The decrease of the population however has been stopped since the year 2000. During that period of time the neighbouring county registered an increase of 26% of inhabitants. Meanwhile the size of the apartments increased from 23 m² per capita in 1989 to 36.6 m² per capita in 2003. Nevertheless approximately 3000 apartments, mainly in the prefabricated slab style buildings remain empty. Almost 2,000 of them will be destroyed in the coming years. In 1989 only 0.3 m² of shopping and trade facilities per inhabitant were available. With the construction of many shopping centres and malls in the last couple of years this number has increased to 1.6 m² per inhabitant. Thus nearly 260.000 m² of shopping and trade facilities were developed in existing and new buildings, in and around Rostock.

To cover the spatial extend of the described developments and the changes in land use different remote sensing sensors and image analysis techniques were used. The geographical focus of the described research will be the city of Rostock. Suburbanisation and urban sprawl into the neighbouring counties will not be covered. The size of the city of Rostock is 181 km². 27 % of the city is covered with forest and 9 % by water.

2. LAND USE CLASSIFICATION 1989 AND 1995 WITH SATELLITE DATA

For the land use classification Landsat TM and SPOT satellite data was acquired for the years 1989 (12.6.1989) and 1995 (31.7.1995). The preprocessing of the data included geocoding and data fusion between the Landsat TM data and the SPOT scenes.

Multispectral land use classification and post classification change detection with Landsat TM data is a common approach, e.g. Green et al, 1994. However only a limited number of land cover classes may be determined accurately by a conventional multispectral classification.

Therefore in 1998 a visual interpretation approach was chosen, which is used to generate a consistent and accurate land use map, such as the CORINE project, Mohaupt-Jahr et al. 2004. The first and most important step of a visual interpretation is the definition of the target scale and the development of an interpretation key which is especially adapted to the goal of the interpretation and the image data as well. An interpretation key has to fulfill different and sometimes contradictory demands. The most important ones are completeness, no crossovers, same degree of interpretation accuracy for all classes, consistency within the chosen scale, third party usability, and the methodological separation of land cover and land use, Meinel and Hennersdorf, 2002.

The developed interpretation key is a three level hierarchical key. The third level is defined only for four housing classes. The minimum mapping area is set to 0.5 ha due to the spatial resolution of the satellite imagery and the mapping scale of 1:50,000. The interpretation key with a total of 19 different classes covers all land cover units within the scene. A good visual discrimination between the classes was given high priority in the definition phase of the classes, in order to obtain a high quality result. Another aspect was the definition of broad classes which could be used for a wide range of users. Additional vector data for “difficult” land use classes, such as covered landfill sites, peat bogs, and military property was provided by the city department of environmental protection.

The visual on-screen digitizing is without problems, if the land cover / land use of a certain object is homogeneous. For heterogeneous objects, three cases may be separated:

- a certain land use of an object is spatially dominating within a polygon, e.g. a small shopping centre may be within the class of suburban single houses.

- a certain land use class is not spatially dominating within a certain polygon, but it is dominating due to the structure of the land use and ecological reasons, e.g. the delineation of peat bogs is not only based on visual boundaries but also on background knowledge.
- a land use class is defined independently upon the land cover due to administrative reasons, e.g. a forest within a military area is considered to be military or a recultivated and covered landfill is still considered to be a landfill.

The land use interpretation of 1995 was done first. Thereby 1255 polygons, based on their spectral behavior were identified. These polygons formed the basis for the land use interpretation of the 1989 data set. Changes were identified and neighboring polygons with the same land use were dissolved. Minor changes of < 0.5 ha were not digitized as new polygons. Certain changes in land use e.g. housing → commercial cannot be covered with satellite data.

2.1 Results

During the six years between 1989 and 1995 the land use changed in 5.5 % of the whole city. The strongest increase could be observed for commercial and industrial areas with an increase of 267 ha. The strongest decrease was observed at military areas with -291 ha. The change detection based on satellite data was quite successful; however the scale of 1:50.000 is only suitable for general trends. For more detailed investigations data of higher spatial resolution is required.

3. LAND USE CLASSIFICATION 2002 WITH HRSC-AX DATA

The HRSC-AX camera system is based on the three line scanner principle, originally developed by the DLR for the planetary MARS'96 mission. The nine CCD-lines are arranged at specific viewing angles with five CCD-lines providing the stereo capabilities and four CCD-lines for the multispectral information. For full details of the camera systems, see Neukum et al, 2001

HRSC-AX image data for the city of Rostock was flown at the 9./10.04.2002. The ground resolution of the nadir channel was 16 cm. The DLR delivered a merged and optimised RGB-image with a ground resolution of 16 cm. The digital surface model (DSM) was processed with a z-resolution of 10 cm and a ground sampling distance (GSD) of 1 m.

3.1 Visual image interpretation

The developed interpretation key is a three level hierarchical key for a target scale of 1:5.000. This scale was a compromise between the interpretation effort (cost) and the degree of detail. The interpretation key is compatible with the prior satellite image interpretation. This could be realized by differentiating the third level in more detail. The extended interpretation key has 40 land use classes. Additional vector data was also provided.

Due to the date of the aerial survey in early April the scene is not well suited for a land use classification, e.g. deciduous trees are without leaves and garden land, barren land as well as many agricultural fields are not covered with vegetation. However a total of 9,965 land use polygons were digitized during this project within three month. The bandwidth between small

polygons, e.g. a tiny road end with 68 m² and a mixed forest with 22.013.280 m² is quite big.

4. SEALED SURFACE CLASSIFICATION WITH ECOGNITION

“A soil is considered to be sealed if it is covered by an impervious material. Thereby sealed surfaces may be divided into build-up areas and undeveloped areas. Besides fully sealed surfaces such as buildup areas and areas covered by concrete or asphalt, partly permeable surfaces such as open celled pavers which allow for a reduced growth of plants are considered to be partially sealed surfaces.”

This broad definition of sealing requires a precise mapping of the sealing which contains information about the type of the building development as well as the ground cover type. Usually this type of information is not available therefore an average degree of sealing per land use or land cover class is applied. This method can be used for all types of land use classifications. The accuracy of the determination of degree of sealing depends largely upon the quality of the data and the mapping scale. An empirical readjustment of the average degree of sealing per land use class is advisable for every classification.

A big disadvantage of this approach is that all polygons of one land use class have the same degree of sealing. Due to this reason an approach shall be used that obtains the sealed area directly from the multi spectral image data as well as other additional information. The degree of sealing will be calculated afterwards individually for each polygon of the visual interpretation.

For the determination of sealed surfaces from multi spectral remote sensing data different more or less complex strategies have been used in the past. Based on satellite data simple vegetations indices, multi spectral classifications, knowledge based classifications were successfully implemented in a number of studies. For high resolution aerial images such pixel based methods get to their limits, because they only rely on the spectral properties of each pixel. To overcome this problem region based classification methods were developed in the last couple of years, e.g. Benz et al., 2004. Thereby a multi level segmentation procedure is used to generate bigger image elements before the classification. The classification procedure may use additional data sources and rules. Through membership functions it is possible to define fuzzy logic rules, after which certain classes may be formulated. The ability to incorporate knowledge about the neighborhood of each segment not only in the classification procedure but also in the segmentation phase is another key difference to the conventional pixel based classification approach, e.g. Benz et al., 2004.

4.1 Preprocessing

The total amount of the 55 GB HRSC-AX data set cannot be handled with the eCognition software at once. Therefore the original data set with ground resolutions of 0.16 m for RGB, 0.5 m for IR and 1 m for the DSM was resampled to a common ground sample distance of 1 m. 16 tiles of all data sets of approximately 4 * 4 km were generated as a compromise between performance and the number of tiles.

The vector data of the visual interpretation had to be reclassified into three classes: sealed, partially sealed and not sealed. For the discrimination of vegetated surfaces and non vegetated surfaces the NDVI was calculated as an additional layer. Thereby one

has to consider that the different spectral bands of the HRSC-AX are not inter calibrated. This causes very unrealistic NDVI values by using the original values of the red and the NIR channel. After dividing the red values by two the NDVI-values are within the normal range, e.g. $NDVI < 0.2$ no vegetation, $NDVI$ -values > 0.6 intensive vegetation. Finally six spectral layers (R, G, B, IR, NDVI and OHM) and one thematic layer from the previous visual interpretation could be used for the segmentation and classification.

4.2 Classification procedure and strategy

The segmentation parameters were determined iteratively and empirically. Normally an image should be segmented with different scale factors, thus creating different levels in order to cover the hierarchical structure of image content. With the integration of the visual interpretation as an additional hierarchy level such a procedure was not necessary.

The image segments are the fundament of an object oriented classification. Beside its spectral information every object is characterized by a large number of statistical information of its size, neighbors etc. This information may also be used in the classification. To minimize the classification effort the object catalog and classification rules were kept as simple as possible. Based on the visual interpretation and general knowledge several assumptions were made at the creation of the object catalog and the fuzzy-logic rules, e.g.:

1. Roofs and traffic areas for the moving and stopped traffic are generally considered to be sealed surfaces.
2. agriculturally used land, water management areas, beaches and dunes are generally not sealed.
3. Shade gets associated to the adjacent polygon by a probability function, if the classification accuracy of any class for the specific polygon is lower than 30%.

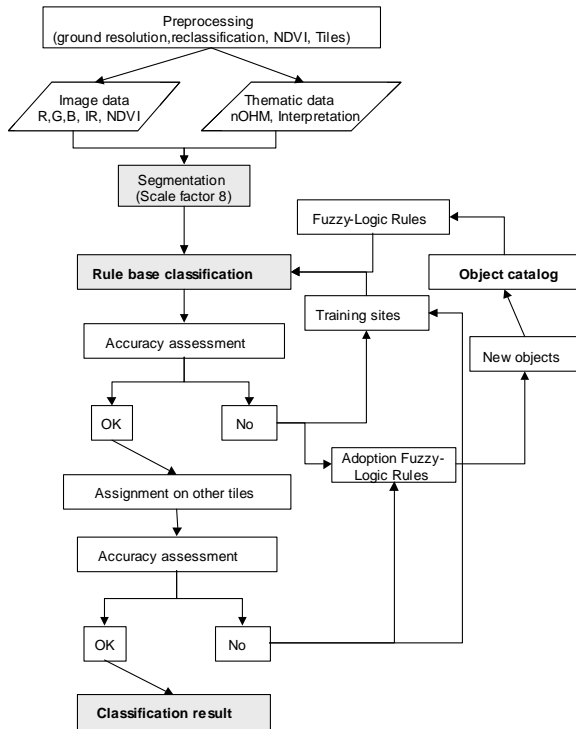


Figure 1: eCognition classification workflow

For each class representative training sites were selected, which are necessary for the nearest-neighbor method. The whole object space has to be covered with the training site or by fuzzy-logic rules to minimize erroneous classified segments. This is of special importance, because the whole city could not be classified at once. Due to two different flight dates of the HRSC-AX camera, imaging conditions and differences in the radiometric processing chain, the radiometry between the northern and the southern part of Rostock is different. Therefore two complete sets of training sites were necessary for classification of the whole city. The object catalog had to be expanded iteratively to include all possible objects and signatures within the classified urban area. At the same time it was necessary to amend the fuzzy logic rules and training sites for tiles in which certain objects uniquely occur. The completed set of rules was finally applied to all the tiles, to obtain a classification with common rules for the whole city.

Due to the different signatures of roofs (red, black, gray, white, sun exposed, sun shaded, flat roof, steep roof) several sub classes had to be defined. A subject of special difficulties were roofs of small and flat shacks within allotments, because they could not be identified in the object height model properly. Therefore an extra class was introduced which also incorporated geometrical parameters, in this case a right-angled form of the roofs and a roof area $< 50 \text{ m}^2$.

4.3 Results

Based on a visual accuracy assessment sealed areas could be properly identified with an average accuracy of 85 – 90 %. Thereby it has to be mentioned that the sealed different objects (streets, ways, roofs and sport places) could be identified with different accuracies and reliability. For example sealed surfaces within allotments were under estimated, because the gardening lots could be spectrally as well as with the object height model barely separated from the buildings and small paths.

Streets and pathways on the other hand were determined as sealed easily with a high level of accuracy. The accuracy of the determination of buildings is quite often limited by the quality of the object height model. The quality of the OHM however is limited by the quality of the DSM, which shows some artifacts and erroneous values due to the processing of the data. Similar problems were reported from other sources, e.g. HOFFMANN et al., 2001.

The determination of the degree of sealing of the visually interpreted land use polygons was done in two steps. In a first step a reclassification of the object oriented land use classification into three classes: sealed, partially sealed and non sealed segments was performed. In a second step the percentage of the sealing per land use polygon was calculated by an overlay operation. This value was added as an additional attribute to the land use polygons.

5. CHANGE DETECTION

The main focus of the comparison between the current land use data set 2002 and the satellite data interpretation of 1989 and 1995 is on the increase of buildup areas during that period of time. In contrary to the land use interpretation of the satellite image data from 1989 and 1995, the HRSC-AX data set of 2002 has a much higher ground resolution. For a change analysis this has several consequences. The interpretation key is not identical, so a comparison is only possible at the first or the second level. Linear elements such as traffic lines (roads,

railways etc.) except the interstate highway were not covered by interpretation of the satellite images, because they were below the ground resolution of a pixel. However the road and path network amounts to 9 % of the total area. The minimum size of a land use polygon of the interpretation of the aerial data is much smaller than the one of the satellite images. Green areas around buildings were not separated, hence whole settlements and commercial areas were completely digitized as a single unit during the satellite data interpretation. This leads to an increase of the buildup areas with the satellite data interpretation compared to the interpretation of the aerial images.

Due to the pixel size of the satellite data the positional accuracy of the digitization of the satellite images is approximately $\pm 20 - 30$ m and thereby far less accurate than the digitized aerial image of 2002 with a positional accuracy of 1 m. For the change analysis of the urban growth a special procedure for the identification of the newly sealed areas was developed, which identifies the newly sealed areas based on a polygon overlay procedure with certain rules, see figure 3.

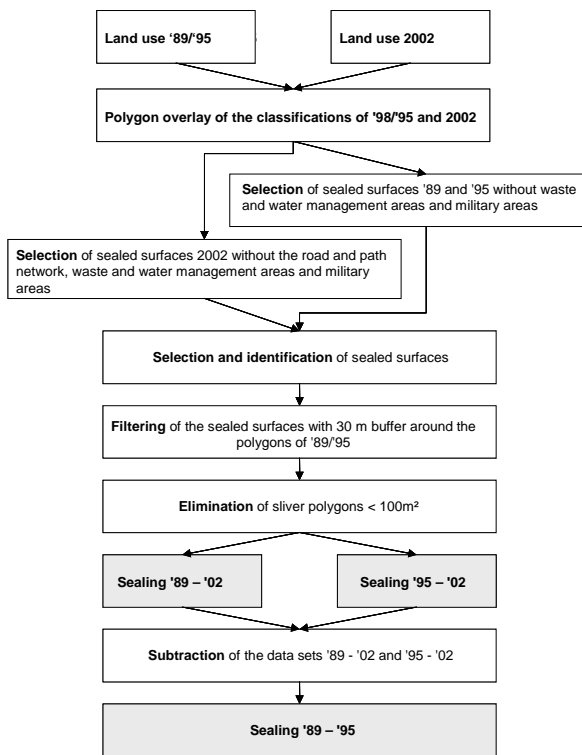


Figure 2: Change detection workflow of urban growth

The chosen approach is a rather conservative one, because new sealing through the construction of new roads can not be determined. This is due to the fact that these linear features were not mapped in the satellite data interpretation of 1989/'95. Also because a whole neighborhood including gardens and greens were classified as build up areas in the satellite data interpretation, further construction and sealing within this area can not be determined by the change detection algorithm. The 30 m buffer around the 1989/'95 polygons classified as build up areas is a compromise between digitization accuracy of the satellite land use interpretation of 1989/'95, which may lead to sliver polygons and real new urban growth and construction which often occurs at the borders of existing build up areas.

Furthermore ca. 81 ha of barren land were mapped by the visual interpretation. Most of these areas have to be considered as sealed in the current sealing balance, because many of these areas are construction sites. This means, the total amount of sealing by urban development is somewhat bigger during the investigated period of time than it could be scientifically proven with the above discussed method. The results are summarized in table 1 and mapped in figure 4.

Table 1: Increase of sealed surfaces between 1989 und 2002

	Increase of sealed surfaces [ha]		
	1989 - 1995	1995-2002	1989 - 2002
Single houses	6.93	103.91	110.84
Town houses	2.79	18.04	20.83
Großblockbebauung	0.09	1.65	1.74
Mixed usage	1.66	13.27	14.93
Commercial and industry	55.22	26.07	81.30
Parking lots	51.3	22.91	74.10
Sum	117.99	185.85	303.84

To sum up, between 1989 and 2002 two different phases of sealing in the city of Rostock can be determined. In the first phase between 1989 and 1995 the planning and development of new industrial parks and shopping malls were in the foreground, while the construction of single family houses took place outside the city limits. In the second phase between 1995 and 2002 larger single family houses were also constructed within the city limits. The development of new industrial parks and shopping malls has declined meanwhile.



Figure 3: Sealed surfaces in Rostock between 1989 and 2004

Compared to the change detection with satellite data, see chapter 2.1 the increase in sealing between 1989 and 1995 for commercial and industrial areas is much lower (only 40 %) with the combined satellite/HRSC approach. This is due to the fact that the definition of sealing depends upon the scale. For instance vegetation between the buildings is not considered to be sealed with the combined satellite/HRSC approach.

6. NORMALIZED OBJECT HEIGHT MODEL

Information on building heights is not only important for the above described classification procedure but also for 3D-city models and other applications. In the processing chain of the HRSC-A data the DSM is automatically generated. The vertical accuracy of the HRSC-DSM is quoted to be around 20 cm, Neukum, 2001. A comparison on 120 survey points in selected areas of the city limits with a vertical accuracy of ± 0.1 m on road crossings, parking lots etc. yielded an average deviation of 0.15 m with an accuracy (standard deviation) of the DSM of 0.35 m. Thereby points with gross errors in the DSM, e.g. caused by cars or neighbouring trees were eliminated.

Due to the fact that especially in shaded areas homologue points are difficult to find, the photogrammetrically determined digital surface models of buildings and other elevated objects don't have sharp edges but fade out into the surrounding. This holds also true for the HRSC.

In recent years most of the research conducted to filter the terrain data to remove above ground man made or natural features in order to obtain the "true" digital terrain model has been done on laser scanning data. Thereby a number of techniques have been developed. Among these procedures are: spline approximation, linear prediction or morphological filters. The determination of a high resolution normalized object heights of buildings and trees (nOHM) may be divided into five different steps:

1. Filtering of the DSM in order to separate the ground points from elevated points (trees, buildings ...).
2. Interpolation of the ground points to a smoothed digital terrain model (DTM).
3. Calculation of a "sink model" (negative difference between the digital terrain model and the surface model). The sinks reveal the lowest points and are important for a hydrologically correct DTM.
4. Addition of the sink model and the smoothed digital terrain model to obtain a normalized digital terrain model (nDTM).
5. Subtraction of the digital surface model from the normalized terrain model to obtain the normalized object height model (nOHM).

The filtering of the DSM was done with an almost automated approach with no manual input. The automated approach is composed of a set of filters, which separate the ground points from elevated points. Thereby in a first step a Sobel filter detects the relevant edges. Afterwards a morphological filter (closing) is applied by a combination of a maximum filter and a minimum filter on the binary image to detect and remove unwanted objects. The necessary thresholds were determined empirically, based on preliminary tests on several sites with different terrain types in the city of Rostock. The thresholds are valid for the whole city. The remaining ground points are visually checked for problem areas such as large flat industrial buildings. To reduce redundant points the output is resampled to $5 * 5$ m. 4.1 million points was generated automatically. The average point spacing between adjacent points is 35 m, the maximum distance 350 m. The large point to point distances occurred especially in forests and in densely populated city districts. In these areas the accuracy of the final DTM and the nOHM may be poor. Therefore an additional 13,099 points were interactively selected in zones where the automated approach did not yield enough points.

Another approach to enhance the DTM accuracy was the integration of additional points derived through the use of a geodetic GPS receiver Leica GPS 1200 mounted on top of a car. Approximately 350 km of the Rostock road net was covered from 28.09.2004 – 05.10.2004. The GPS-measurement rate was 5 Hz and a total of 144,046 points were recorded. During the post processing of the GPS-data the ambiguities could be solved in 71.9 % of all cases, see Figure 4. Beside these points with centimetre accuracy another 16,544 points were identified with a vertical accuracy of < 1 m through automated and interactive routines. In cases where road segments were covered more than one time, data with the highest accuracy was used for further processing.

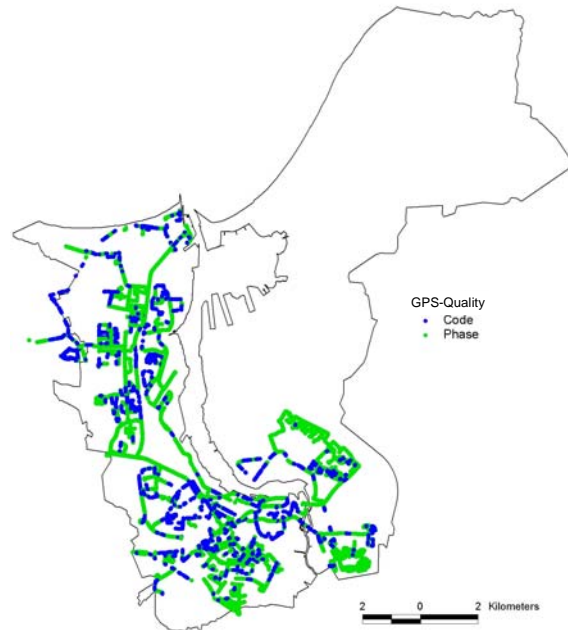


Figure 4: GPS-Survey for DEM-enhancement

The interpolation to a $5 * 5$ m grid was done with a geostatistical approach using kriging techniques. The nDTM and the nOHM were calculated afterwards. Differences between the DTM and the nDTM are shown in figure 5, 6.

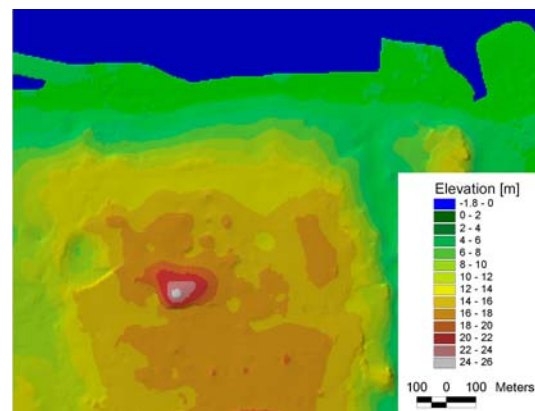


Figure 5: DTM of downtown Rostock

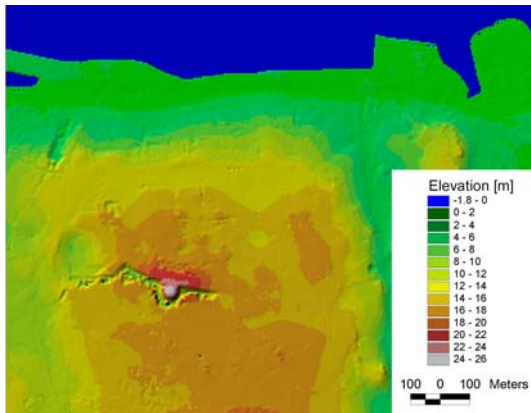


Figure 6: nDTM of downtown Rostock

The quality of the nOHM is limited by the accuracy of the interpolated DTM and the input DSM. Thereby it is worthwhile to mention that the delivered DSM has some artefacts and parts of tall buildings are just missing in the DSM.

The numeric accuracy of the final nOHM was determined by several control measurements of buildings with the hand-held laser distance measurement instrument LaserAce 300. The average height error for buildings (n=16) was 0.87 m. The deviations inherit a systematical error of approx. 4.5%.

7. PFIFF

As shown in the previous chapters, urban areas undergo a continuous change; this change however doesn't take place in the whole town, but in certain developing areas such as construction sites etc. These areas are often relatively small; let's say only a few hectares. The user, especially local agencies, developers and private companies are interested in current data of these "developing spots" with a high level of detail. They also want the data to be delivered digitally and ortho rectified within a few days after an aerial survey. The cost for data per km² from a conventional aerial survey however increases, the smaller the area of interest becomes. Due to these reasons there is a strong demand for economically priced remote sensing data for small areas. PFIFF, a digital airborne remote sensing system, was originally developed by the author to fulfil the special requirements of precision farming. Those requirements – low cost, high amount of detail and rapid delivery – are very similar to those urban users.

7.1 System components of PFIFF

The core of the system by 2005 is a Rollei AIC 45 CIR camera with 5440 * 4080 pixel. The exposure interval of less than 4 seconds of the camera enables photogrammetric aerial surveys (60% end lap) with a ground resolution of > 10 cm. The digital camera is controlled by a laptop, which also stores all the image data. Other important components of PFIFF are the GPS-based flight management system and a survey navigation unit that automatically triggers the images, and records the exposure delay of the camera as well as the approximate parameters of the exterior orientation with an attitude heading reference system (AHRF). The exposure control is coupled with the GPS-clock to ensure a perfect synchronisation with the external high accuracy L1/L2-GPS receiver. For a photo flight the system is temporarily installed in a Cessna 172 with a small ground hole of ca. 12 cm in diameter, Grenzdoerffer, 2004.

In 2004 several local hot spots were covered with PFIFF requested by different city departments of Rostock. E.g. current information of the development process of the new harbour (3 flights) was requested by the cadastral division, see figure 7.



Figure 7: Harbour construction, 14.4.2004, 16 cm GSD, mosaic of 12 images, covered with PFIFF

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