PHOTOGRAMMETRIC IMAGE ACQUISITION AND IMAGE ANALYSIS OF OBLIQUE IMAGERY - A NEW CHALLENGE FOR THE DIGITAL AIRBORNE SYSTEM PFIFF

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ABSTRACT: Due to the intuitive perception of the oblique view to humans, recently oblique images come in the focus of photogrammetrists again. Also new flexible digital airborne camera systems allow for the easy collection of such imagery with a photogrammetric quality. In the article the application potential of oblique images, the digital airborne remote sensing system PFIFF, and two test flights with oblique and oblique stereo images are presented. The data processing, display and measurement within oblique images from different perspectives requires new software such as Multivision.

1. INTRODUCTION

1.1 Oblique images - a new data source for photogrammetry and GIS

In the past oblique images were generally taken for visualisation and interpretation purposes, rather than for metric applications. An exemption is the military sector were oblique images are a standard for reconnaissance purposes since a long time, e.g. WELZER, 1985. Thus oblique images were generally outside of the focus of photogrammetrists.

The use of standard vertical orthoimages as a topographic background in a GIS is nowadays very common, thus generating a strong demand for current photogrammetric airborne and high resolution satellite data. Planners, administrative users and the general public use the available orthoimages, e.g. in Google Earth and other similar services mainly for orientation and visual inspection of selected features. Yet vertical orthoimages may not be read easily by everyone. Due to the intuitive use of the oblique images, which is similar to the common human perspective, these images are very attractive to decision makers, as well as for the general public. To fully exploit the information from the oblique perspective, a minimum of four images from all sides have to be acquired and managed.

Standard GIS-packages do not support oblique images, due to their geometry with varying scales, therefore new viewers and software packages have to be developed to guide the users and provide them with the necessary functionality.

Oblique images are an indispensable tool for the following general uses, which will be subsequently described in more detail.

- Tax Assessment & Building Deviation
- Urban and infrastructural planning
- Management of military und security operations
- Critical infrastructural protection
- Cadastral capturing and management

Tax Assessment & Building Deviation

- Accurate measurement of areas, building facades and constructions of the capital assets
- Effective identification, measurement and documentation of deviations
- This results in an increase of the tax revenues for built estates

Urban and infrastructural planning

- Comparative measurements of buildings and structures
- In landscape architecture and urban planning it can be used to capture and evaluate real estates or for the build-up of pylons
- For the telecommunication planning it can be used to do line of sight calculations

Management of military und security operations

- Immediately availability of information about critical locations
- Accurate visualisation of these locations
- Identification of surrounding areas and infrastructure
- Measurement of accesses and openings
- Planning of access and exit routes

Critical infrastructural protection

- MultiVision is a valuable tool for the following facilities
  - Airports, ports, railroad stations, malls
  - Power authorities, military and police facilities
  - Government buildings, hospitals, prisons
  - Dense populated areas, tower blocks

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– factory premises and industrial areas

Cadastral capturing and management

- Accurate capturing and organisation of cadastral activities in rural areas
- Perfect for 3D cadastral projects

Additionally oblique images can be used to texture 3D-buildings and 3D-city models. These textured buildings can than be used as realistic objects in 3D visualisation projects.

The Microsoft Virtual Earth viewer (Microsoft, 2007) provides high resolution oblique images for many cities around the world, but only from one viewing perspective at a time. Viewer solutions from Pictrometry Inc. (Pictrometry, 2007) and Multivision Inc. (Multivision, 2007) allow for several perspectives of one object simultaneously. Additionally these specialized viewers provide additional features, such as the measurement of distances and the integration of addition GIS-data. In chapter 4 the functionality and the workflow of the MultiVision software will be presented in greater detail.

The system PFIFF, a digital airborne remote sensing system developed by the author, will be described in detail with special respect to demonstrate the photogrammetric potential of PFIFF. The focus of the paper will be the exploration of possibilities of oblique (stereo) images, e.g. for visualisation or automated building texturing, as well as for the vitality analysis of trees along the roads.

2. PFIFF

PFIFF, a digital airborne remote sensing system, was originally developed by the author to fulfil the special requirements of precision farming (Grenzdörffer, 2005). The special advantage of PFIFF compared to standard photogrammetric frame cameras is the possibility to take oblique images.

The core of the system since 2005 is a digital SLR colour camera, the Rollei AIC45-CIR (Aerial Industrial digital Camera). The CCD-sensor H25 from Phase One has a net resolution of 5.436 * 4.080 pixels (22 Megapixel), see Table 1 for the technical details of the camera.

Table 1: Technical parameters of the digital Rollei AIC-CIR 45 camera

	Rollei AIC 45
Camera type	Rollei AIC with fixed digital back
Resolution [pixel]	5.436 * 4 .080
Pixel size	9 µm * 9 µm
Sensor size [mm]	48.96* 36.72
Colour depth per channel	16 Bit
Colour mode	RGB or CIR
min. exposure interval	ca. 4[1] sec.
Weight (incl. lens)	ca. 1.500 g
Connection to computer	Firewire, Barebone PC
Software	Phase One 3.1

[1]value for two consecutive images under airborne conditions

With the exposure interval of less than 4 seconds under airborne conditions, the Rollei AIC camera enables photogrammetric aerial surveys (60% end lap) with a ground resolution of > 10 cm. The digital back works together with a Rollei AIC-camera body and a Schneider Super Angulon 2,8/50mm HFT lens with a min exposure time of 1/1.000 s. The digital camera is controlled by a barebone PC with a storage capacity of 400 GB which stores all the image data (up to 6.000 images) via firewire connection.

The camera may acquire images either in RGB or in CIR. Therefore the IR-cut filter on the top of the CCD-sensor was removed. The different colour information of the CCD-sensor is gathered via a Bayer-pattern. For a CIR image a band filter is mounted on top of the lens, which filters out the blue light (< 520 nm). The green, red and infrared light up to a wavelength of 1.050 nm passes the filter onto the sensor. As a result the green light and red light sensitive CCD-elements also gather infrared light. These infrared light components have to be separated in the development process. Yet the infrared light sensitivity of the sensor is much stronger than in the visible light. For a similarly enlightened image in the RGB-mode and the CIR-mode the amount of the incoming light has to be lowered by 3 f-stops for the RGB-image.

Other important components of PFIFF are the GPS-based flight management system and a navigation unit that automatically triggers the images during a flight strip according to the pre defined end lap. During the strip the optimal image exposure interval is continuously computed and the camera is triggered synchronously to the PPS-signal of the GPS-clock to ensure a perfect synchronisation with the external high accuracy L1/L2-GPS receiver. The navigation unit records the exposure delay of the camera. With this approach a constant endlap is ensured under all conditions with the most flexibility during an aerial survey. This approach is quite different to the common approach of a photogrammetric aerial survey, because there the image centres become predefined in the flight planning and they are subsequently flown during the aerial survey.

For a photo flight the system is temporarily installed in a Cessna 172 with a small ground hole of ca. 12 cm in diameter. See Figure 1 for the system design.

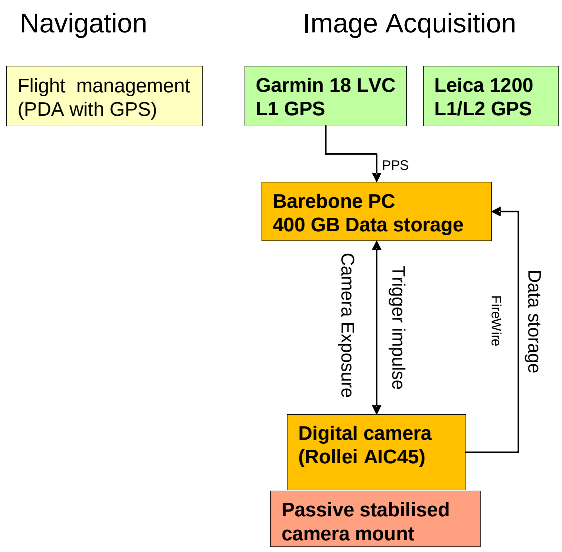

Figure 1: Low-cost remote sensing system PFIFF 2006

For the use of a digital camera in aerial surveys not only the size of the CCD-sensor is of importance, but also many other criteria of the digital camera such as the minimum exposure interval, the external storage capacity, a continuous power source, preview options, the mechanical stability of the sensor (interior orientation), the temporal eccentricity (exposure delay), the reliability and also the radiometric properties have to be considered and determined. Therefore the system has undergone thorough geometric and radiometric calibration procedures. For photogrammetric work the interior orientation of the camera was determined. With the fixed digital back of the AIC45 an on-flight calibration is not necessary. The examination of the linearity, the spectral characteristics of the RGB band filters and the high signal to noise ratio revealed that the radiometric properties of the digital camera are far superior to an equivalent photographic system.

In 2006 a general overhaul of the PFIFF flight navigation system and the flight management system with a fully automatic image triggering was undertaken. The software CartaLinx from ClarkLabs was formerly the basis for the flight navigation, in which the flight lines and the current position of the aircraft were displayed on a laptop to the pilot. The drawbacks of this solution were that the map on the display was always north oriented and the pilot had to rethink left or right on every manoeuvre. Additionally the pilot lacked important information for the navigation, such as current course vs. planned course, critical ground speed etc. Due to these reasons a new software with dedicated features for the pilot was developed. The software runs on a common PDA with GPS. The most important features of the software are automatic rotation of the graphics in the flight direction, automatic zoom functions within and outside the survey area, a graphical display of the current exposure interval of the camera used and most important aerial survey navigation information. The software development was realized in VBA with the GPS-tools vers. 2·31 from Franson S/A.

During the postprocessing the recorded GPS-positions (1 Hz) have to be interpolated to the precise moment of the image acquisition. Due to the long exposure delay of 302 ms (±0.1 ms) of the AIC 45 camera linear interpolation of the GPS-position may be associated with significant errors due to high frequent nonlinear aircraft movements. A comparison of 266 perspective centres, determined either by linearly interpolated 1 Hz GPS-positions and 200 Hz GPS/INS measurement does show this quite well, TABLE 2.

TABLE 2: Deviations [m] of the perspective centres, determined by linear interpolation of 1 Hz GPS recordings and 200 Hz GPS/INS measurements (n = 266)

	X (m)	Y[1] (m)	Z (m)
Average	0.004	0.009	0.015
Standard dev.	0.077	0.104	0.051
Max	0.243	0.581	0.140
Min	-0.175	-0.546	-0.131

[1] East-West, main flight direction of the image strips

With the reengineering of the GPS-based flight management system the exposure delay is now considered during PPS-synchronous image triggering, see
Figure 2.

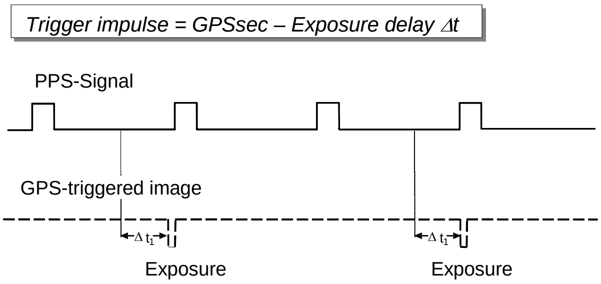

Figure 2: PPS-synchronous image acquisition considering the exposure delay time of the camera

In order to fully automatically trigger images within the survey area, the camera triggering is now tightly coupled with the flight navigation system. The flight management software automatically starts triggering the camera whenever the pilot manoeuvres the aircraft inside the survey area. After the aircraft is outside the survey area the automatic image triggering stops. Because the MS-Windows XP operating system does not support real time applications an additional timer card (NI-6601) from National Instruments was integrated in the computer. The programming of the timer card and the PPS-synchronous triggering was realized with Labview 8.0.

3. OBLIQUE IMAGES

The image acquisition of oblique images requires several changes in the common workflow, from survey planning to image processing and image analysis.

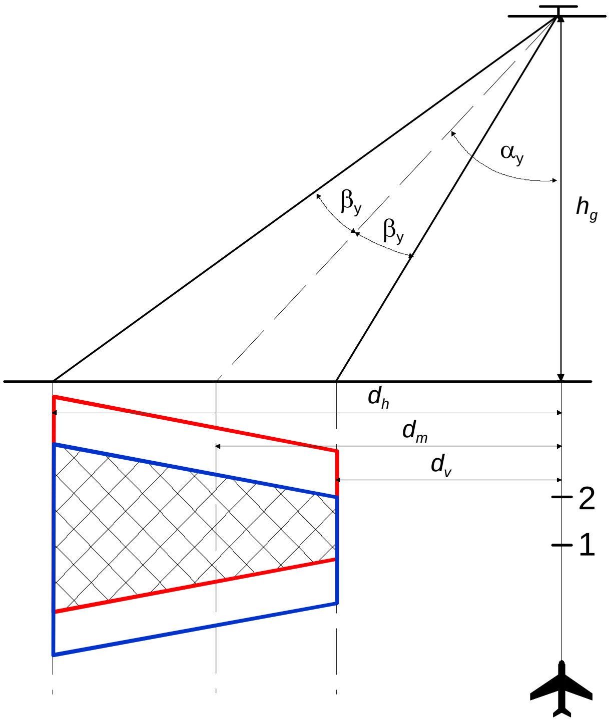

Figure 3: Geometry of oblique images

3.1 Flight planning

In the flight planning for oblique aerial survey several special issues have to be considered. The image scale is not constant throughout the images. In the foreground the ground sampling distance (GSD) is smaller than in the image background. See Figure 3. In the flight planning the altitude above ground and the viewing angle α_y across the flight direction has to be defined. The viewing angle of the lens β_y defines the minimum and the maximum distance d_{max} of the image to the aircraft as well as the image scale for analogue images or the GSD with digital images. The minimum, average and maximal ground resolution is calculated by the following equations.

$$m_{b\min} = \frac{h_g \cos\beta_y}{f \cos\left(\alpha_y - \beta_y\right)}$$

$$m_{avg} = \frac{h_g}{f \cos\alpha_y}$$

$$m_{b\max} = \frac{h_g \cos\beta_y}{f \cos\left(\alpha_y + \beta_y\right)}$$

The distance of the image foreground and the image background to the aircraft is based on the following equations.

$$D_{\min} = h_g \tan(\alpha_y - \beta_y)$$

$$D_{avg.} = D_{\max} - D_{\min}$$

$$D_{\max} = h_g \tan(\alpha_y + \beta_y)$$

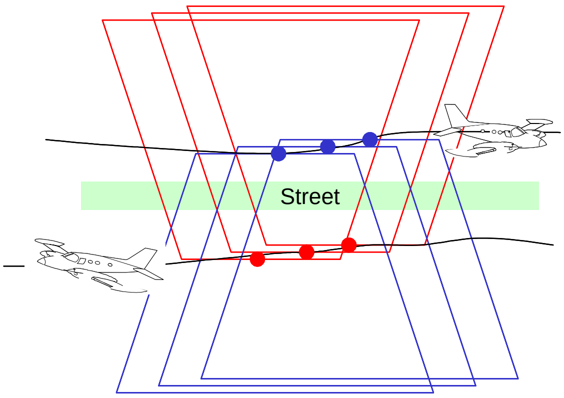

Figure 4: Flight pattern for oblique images of streets, pipelines etc.

3.2 Example oblique images for street trees

On 6th of September 2003 a flight of a 4 km long part of an avenue with trees on both sides was conducted with a ground resolution of approximately 12 cm, Grenzdörffer, 2004. The purpose of the flight was to investigate the possibilities to obtain information of the vitality of trees, the street and the surrounding from nadir looking images as well as from oblique images, see Figure 4 for the flight pattern. Therefore the central flight line along the street was designed to gather nadir looking data. For the oblique images the camera was turned around 90 degrees and held out the window of the airplane manually. On small aircrafts such as a Cessna 172, the wheels of the aircraft maintain outside during the flight. Due to this fact oblique images out of the window could not be taken at the anticipated 45° angle. Instead the looking angle was approximately 60° in omega. To become oblique stereo images with and end lap of 60% the automatic trigger control of the flight management system had to be reset accordingly.

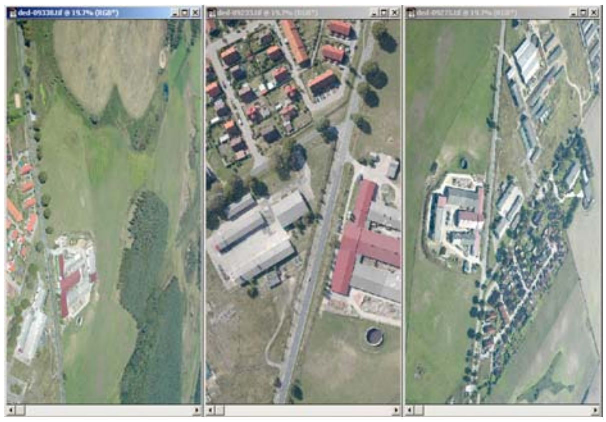

Figure 5: Example of nadir looking and oblique images of a street

At first the nadir looking image strip was processed by means of a standard aerotriangulation. The georeferencing of the oblique images was more complicated, because tie points in neighbouring images could not be found automatically in the first instance. This is related to the fact, that the starting values of ω and φ of the hand held images were unknown. After a manual definition of a minimum number of tie points with a selected number of oblique images, a preliminary triangulation was conducted to obtain approximate angles in ω and φ. Thereafter the automatic tie point generation algorithm worked fine. Due to the apparent differences in the scale within the oblique images the precise determination of the ground control points was difficult. Nevertheless the results of the aerotriangulation of the oblique images were within 60 cm RMS at the GCP's. The most interesting aspect for the interpretation of the trees and other features along the street is the stereo view of the oblique images, because an orthorectification does not yield the full information.

3.3 Oblique stereo images

With direct georeferencing through GPS/INS the problems of manual tie point selection and cumbersome image rectification are overcome and the image data may be used e.g. for texturing of 3D city models or other interesting purposes. See figure 10 for the footprints of a strip of oblique images, generated at a test flight in Rostock, Grenzdörffer, 2005. Due to the big overlap the images may also viewed and analysed in stereo, figure 11.

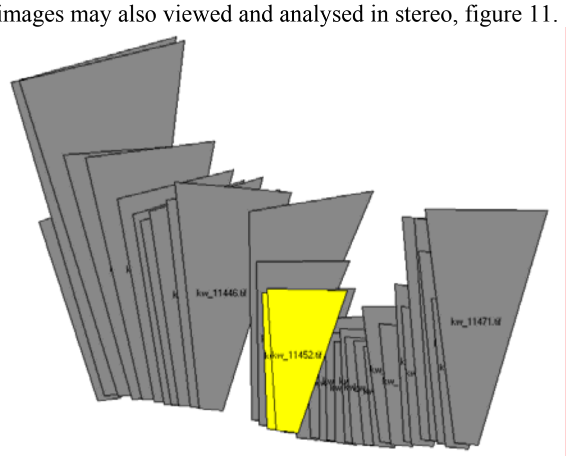

Figure 6: Footprint of strip of oblique images

Due to the highly accurate georeferencing y-parallax is nearly absent (displayed in the lower right part of the screen shot) allowing perfect stereo measurements in the images.

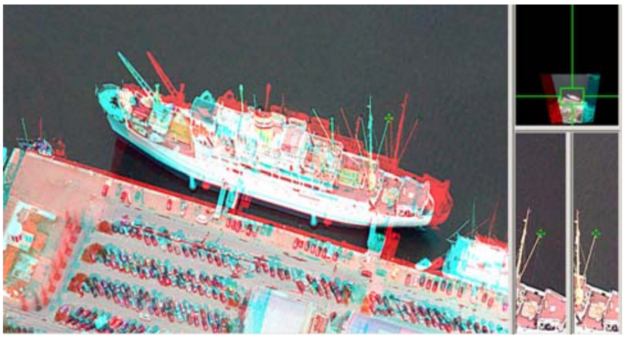

Figure 7: Oblique stereo anaglyph image through direct georeferencing

4. MULTIVISION TEST FLIGHT ROSTOCK

The test flight with oblique images for visualisation and semiautomatic building texturing was undertaken at the 23.11.2006 over the downtown area of the city of Rostock. The complex flight pattern is shown in Figure 8. The average flying altitude was 400 m above ground. The resulting ground resolution in the image center is approximately 15 cm. A total of 78 images with an overlap of approx. 60 % were acquired at the flight.

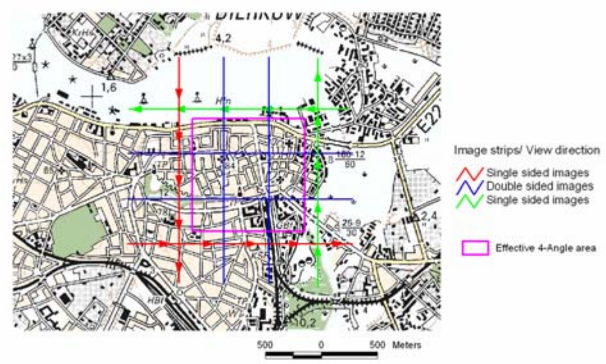

Figure 8: Flight pattern for test flight Rostock 23.11.2006

Due to the low sun angle at the time of flight in late November the image quality in the different view directions is quite different. The radiometric postprocessing included a colour balancing, with individual parameters for each flight direction and a 16 → 8 bit conversion.

5. MULTIVISION

The data analysis of the test flight is done with the Software MultiVision, (Multivision, 2007). Vertical and oblique orthophotos resolved via photogrammetric methods are integrated into a "Site File" to provide an interactive multi-dimension, multi-perspective view of any area, building, structure, and feature. A Site File integrates an orthophoto of a site with its associated oblique photos and DEM. Any selected feature can be viewed in perspective and from any direction. Elements of structured and facades can be accurately be measured for height, width, area, elevation etc. The terrain can be accurately measured for dimension, distances, slopes, elevation and declination.

The determination of the exterior orientation of the oblique images may be by sampling control points, like the method by which orientation is carried out for aerial photos that undergo rectification and orthophoto generation. The program displays an orthophoto and an oblique photo at the same time, so that control points can be sampled on both of them simultaneously. The solution program, MV-SPECIAL ONE, is designated to calculate these parameters efficiently, without requiring any further flight data. The solution is based on the collinearity equations. Control points can be taken from photogrammetric maps, or from any other accurate source. The accuracy of the control points will determine the accuracy of the orientation solution. Orientation of analog aerial photos requires internal orientation, such as input of fiducial marks.

The determination of the exterior orientation of oblique aerial photos can also be carried out using a GPS/INS system. To sum up: Multivision enables a photogrammetric solution for any type of photo/camera. The type of photographic system and solution will ultimately determine the accuracy and resolution of the solution.

The average absolute positional accuracy of the oblique images is related to several factors such as the available ground control points from the orthophoto, the accuracy of the underlying DEM and the accuracy of the interior orientation of the selected camera. For the Rostock project ground control points for the oblique images were derived from the underlying orthophoto with a GSD of 50 cm. The average of the absolute positional accuracy of the images, determined by visual inspection, is generally between 2 - 3 m, while some images are even worse. If the flight is conducted with a GPS/INS the absolute positional accuracy is better, e.g. Grenzdörffer, 2005. The relative accuracy, necessary for the measurement of the height or the width of buildings are only partially related to the absolute accuracy and generally much better.

The program operates in DTM environment, thus enabling to make various calculations for locating the user's relevant oblique photos. Multivision operates in correspondence with a GIS (for example, ArcView). The GIS operator can make geographic queries; once a datum from the GIS is displayed (such as an address, coordinate, polygon, etc.) – four oblique aerial photos for the specific coordinate will appear on screen, Figure 9.

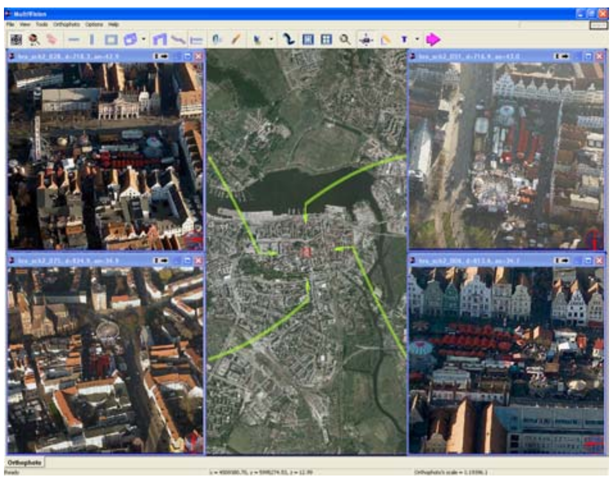

Figure 9: Multivision Main Screen

5.1 Texturing 3D-buildings with aerial imagery

Texturing buildings with the aid of aerial imagery may be done in many different ways. Wide angle vertical images provide an oblique view at their edges, which may be used for automated texture extraction, Zebedin et al. (2007). Alternatively modern 3-line scanners such as the HRSC-A or ADS 40 provide oblique views with their forward and backward looking channels, enabling an automated generation of 3D-textured facades, e.g. Hirschmüller et al. 2006, Woolpert SmartView^{TM} (2007).

5.2 3D-building Data for Rostock

A simple 3D-building model (LOD 1) of the city of Rostock is available on the basis of a HRSC image data and official cadastral information (ALK). Due to the data structure of the ALK, building objects in the ALK may represent more than one building in reality. Therefore buildings were split up based on the true orthophoto of the HRSC. Additionally several landmarks, such as church were modelled individually.

However the usage of a simple block model is limited, e.g. for the determination of road noise absorption of buildings according to new EU regulations (EU Directive 2002/49/EC on Environmental Noise). For city planning and other purposes a 3D-city model should have at least several roof types and textured facades. The common texturing of facades with terrestrial photographs is quite cumbersome. Therefore an aerial survey with automated texturing is the most elegant approach.

The texturing of the single buildings within Multivision is done on a per building approach. Thereby CAD-buildings are incorporated into the software and the facades are clipped automatically from the different views, see Figure 10.

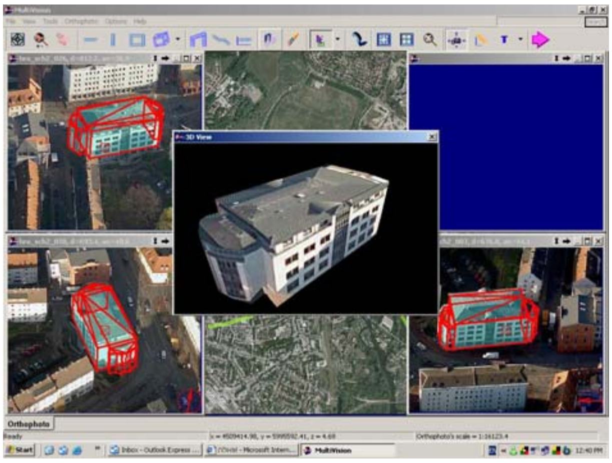

Figure 10: Semiautomatic generation of building textures

Due to a lack of standardized solutions for data transfer between different 3D-software packages 3D-data conversion is always a bottle neck in the development and texturing of 3D-city models. Independent standards such as the CityGML–Standard within OGC (CityGML 2007) are currently under development.

6. OUTLOOK AND FUTURE WORK

The automation of the relative and absolute orientation of oblique images is still an issue of intensive research. Thereby the differences in scale and overlap have to be considered. Läbe and Förstner (2006) demonstrated promising results, also with PFIFF airborne oblique images.

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