D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

DIGITAL COLOUR ORTHOPHOTOS FOR BOOMTOWN DUBAI

Alfred Mehlbreuer, Ralf Schroth, Uwe Weidner, Mohammed Al Zaffin*
Hansa Luftbild GmbH, Elbestraße 5, D-48145 Münster, Germany
* Dubai Municipality, P.O. Box 67, Dubai, U.A.E.

ABSTRACT

Dubai Municipality is actively introducing digital orthophotos for solving actual planning needs. Past experience revealed that already available map products are very soon outdated due to a booming economy and comprehensive building activities. Therefore, two aspects became relevant: The image data have to be up-to-date and they have to be of commensurate geometrical accuracy since they will be used in conjunction with other numerically recorded survey data. Ortho-image data will definitely provide an essential component for an urban GIS.

Hansa Luftbild was entrusted by Dubai Municipality to produce 1,630 digital colour orthophotos at scale 1:1,000 covering the major development areas of the Dubai Emirate. Each digital orthophoto represents an area of 1 by 1 km; the ground resolution is 10 centimetre per pixel. The complete set of image data including image pyramids requires a storage space of about 675 gigabyte. Other components of the project were GPS supported aerial photography, aerial triangulation with the incorporation of photo exposure centres, measuring of a high quality digital terrain model, and scanning of diapositives by means of a photogrammetric scanning device.

This paper describes several aspects of the actual orthophoto production and gives an outline of future activities as well as plans of Dubai Municipality to further enhance geo-information.

1 PROJECT OUTLINE

Dubai is one of the seven emirates which comprise since 1971 the United Arab Emirates (U.A.E.). It is the second largest emirate with an area of some 3,900 square kilometres. Known in the region as the “city of merchants“, Dubai has for generations welcomed seafarers and traders to its shores. Today, it is one of the world’s great gold trading centres selling more than one ton of gold each day. Dubai is also home of a large free-trade zone at Jebel Ali, a huge dry-dock complex, and one of the Middle East’s busiest airports. Dubai’s wealth is founded on trade not on oil; it is one of the Gulf’s main business centres.

Administration and planning within the Emirate is organised by Dubai.

Municipality (DM). To be in line with the demands of a rushing economical development, the institution is in the process of modernising and adapting its public services. The agenda of DM foresees to implement and improve key functions in the provision of general services to the public. These services cover, for example, surveying, planning, public works, drainage, real estate, land management and so forth, i.e. typical tasks of a modern local government.

In order to support this objective, a comprehensive aerial survey and updating of geo-information was initiated by the Planning and Survey Section of DM. The overall aim was to provide up-to-date digital information that will be utilised for the authoritative duties of Dubai Municipality, and that will be made available also to other organisations and institutions in the Dubai Emirate.

A major aspect and initial starting point of this challenging program was the production of digital colour orthophotos at a large scale. The objective was to provide image data of high resolution and adequate accuracy that shall be suitable for the generation and updating of vector maps of a general Geographic Information System (GIS) for Dubai Municipality. The GIS hardware was designed accordingly and will consist in its upgraded installation of a network of several engineering workstations with suitable peripherals and a large Windows NT file server. The total storage capacity of the system will be about seven hundred (700) gigabyte. Dubai Municipality is mainly using INTERGRAPH hardware and software for GIS processing (MicroStation, MGE, I/RAS, etc.).

Dubai Municipality entrusted Hansa Luftbild - German Air Surveys - with the realisation of this project; it’s official name is **Dubai Digital Ortho-Photogrammetric Mapping Project 1996**. The agreement stipulates that the contractor shall completely execute and deliver all works and results as specified in the technical specifications within one year. The initial work program was, however, extended by several change orders so that the project was finally completed by the end of June 1998.

The project area covers in its finally adopted extension a size of 1,630 square kilometres; this is nearly equivalent to half the size of the entire Dubai Emirate. The project area is not continuous but separated into several sub-areas. Figure 1 gives an outline of the contract area and its division into orthophoto map sheets of size 1 by 1 km.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

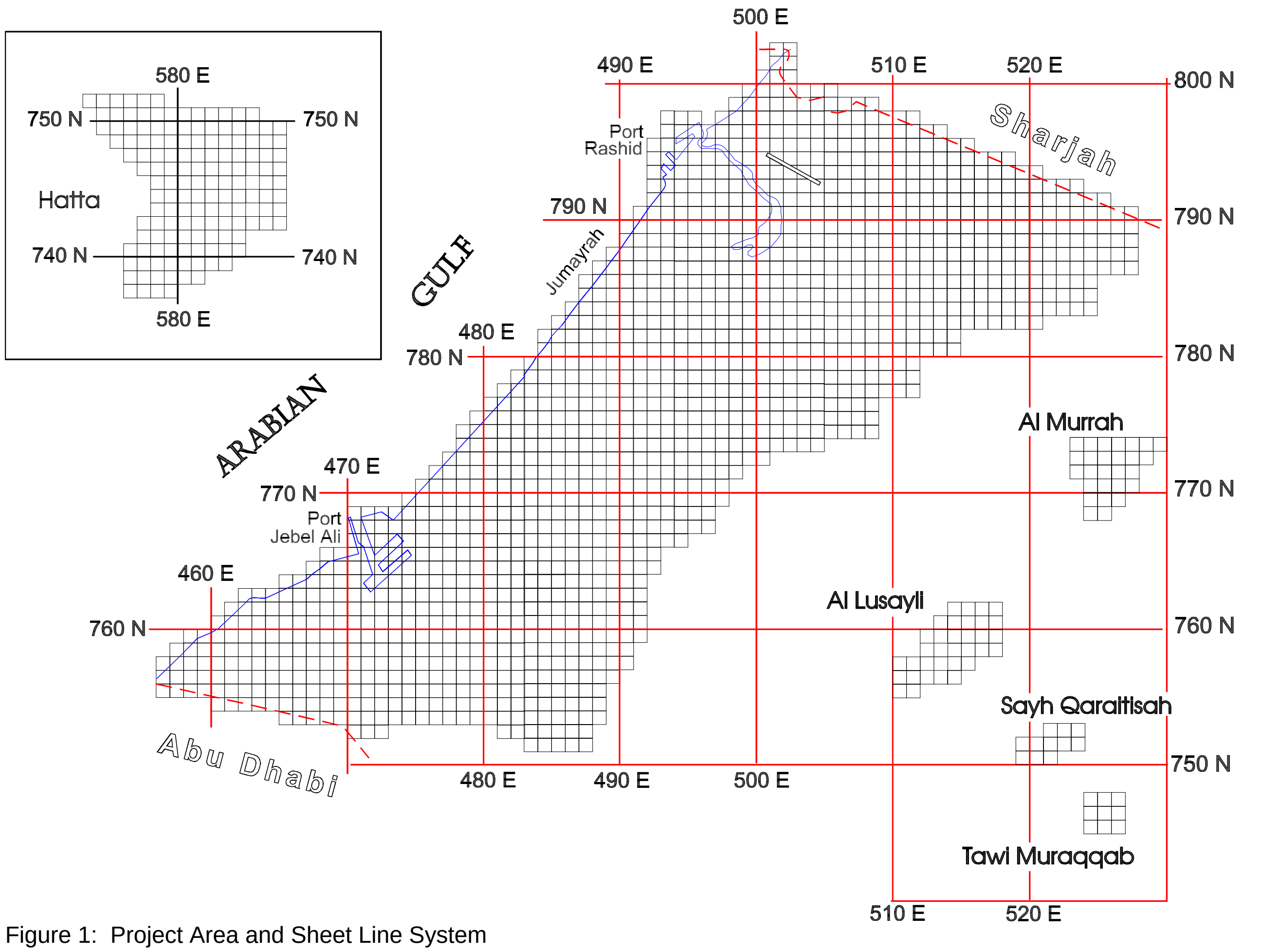


Figure 1: Project Area and Sheet Line System

2 SCOPE OF THE PROJECT

Dubai Municipality requested colour digital orthophotos jointly accompanied by the corresponding image pyramids. Each ortho-image had to cover an area of 1 by 1 kilometre; the final pixel size on the ground was required to be 10 centimetres. So called "true" orthophotos were not required, i.e. the digital orthophotos are conventional.

The project area covers a great variety of scenery ranging from flat desert plains in the outskirts to undulating sand dunes in the southern part of the project area and to the scenic mountains of Hatta. Constructions mainly stretch along the coast, and the central business district embodies high rise structures as in every modern city (see figure 2).

Aerial photography of these quite disparate "landscapes" had to be in colour at the uniform scale of 1:6,500. Hansa Luftbild selected for this purpose a ZEISS metric survey camera RMK Top with a normal angle lens of 305 mm focal length (12 inches). The camera system was furnished with a device for forward motion compensation. Flying height above ground was about 2,000 metres. Survey flights and sheet line based aerial photography was controlled by means of the GPS supported flight navigation and camera positioning system CCNS-4.

Aerial triangulation was employed by PATB-RSG, known as general **P**hotogrammetric **A**erial **T**riangulation software for **B**undle block adjustment which incorporates mathematical models for the automatic detection of gross data errors based on **R**obust estimators, **S**elf calibration of systematic image errors and the simultaneous processing of **G**PS determined camera positions. The overall a posteriori accuracy of aerial triangulation was required by the Scope of Work to be $\sigma_0 = \pm 8$ micrometer at photo scale. This requirement could be fulfilled by AT adjustments for all sub-areas.

The digital terrain model (DTM) was generated by means of "MGE Terrain Modeler", a software package from INTERGRAPH. Input data were regular grid points as well as single spot heights and natural/man-made break lines. The corresponding measurements were carried out by means of analytical plotters.

Scanning of colour aerial photographs, i.e. analogue to digital conversion, was performed by means of the flatbed scanning system ZEISS SCAI. The device is suitable to provide image data of high geometrical accuracy and standard radiometrical resolution.

Digital ortho-rectification of scanned images itself was carried out by means of the module "Base Rectifier" of INTERGRAPH's software for PC and ImageStation. All image data were to be referenced in terms of Dubai Local Transverse Mercator projection (DLTM) with regard to the World Geodetic System of 1984 (WGS 84).

3 IMAGE DATA ACQUISITION

3.1 Aerial Survey Flights

Aerial photography of the contract area was realised within seven flight days between 16 April 1997 and 1 May 1997. The accumulated flying time was about 23 hours. Mission base for all aerial survey flights was Dubai International Airport. The administrative matters were handled by Hansa Luftbild's Branch Office in Dubai after consultation and in close co-operation with the Planning and Survey Section of Dubai Municipality.

The technical aspects of the survey mission were carefully planned in Germany prior to mobilisation. For this purpose, Hansa Luftbild utilised the software package WWMP (World Wide Mission Planning). It allows computation of flight data on the basis of pre-defined project parameters such as focal length, start and end co-ordinates of flight lines, photo scale, overlap and so forth.

Of particular interest to flight planning is the capability of WWMP to compute pre-planned positions of all photo exposure centres. Thus, aerial photography can be planned in the manner of a chessboard pattern, allowing aerial photography of adjacent runs to be carried out without a shift in flight direction.

Transfer of WWMP data to the CCNS-4 system is realised by means of a rugged solid-state data card. As a result, the pilot has available all relevant survey data and can directly control the survey flight on his monitor.

WWMP and CCNS-4 are trademarks of the firm IGI, Hilchenbach, Germany. The flight management system was developed by German aerial survey experts and University staff in close co-operation with Hansa Luftbild.

3.2 Film Processing

The aerial film chosen for the project was the colour-reversal film KODAK Aerochrome MS 2448. It has medium to high contrast, very fine grain, and a resolving power of 80 lines per millimetre at object contrast 1000:1.

The relationship between film grain and processing speed offers high definition, and it is capable of providing excellent ground detail. This was of special importance for this project since low photographic contrast in the desert area alternates with high photographic contrast in the urban area and in the mountainous area of Hatta.

All films were processed in the laboratories of Hansa Luftbild in Germany. This was done to achieve optimum results since the KODAK Aerochrome film is designed for continuous processing by development machines such as the KODAK Versamat 1811. Those automatic processors allow adherence to standard conditions of film development. Chemical composition, high temperature development and processing speed are carefully controlled, thus providing optimum photographic results.

Hansa Luftbild is one of only two companies in Europe which are acknowledged by KODAK as a professional AR-5 laboratory. AR-5 is a recently introduced film development process which uses chemicals that are less deteriorating to the environment.

Fourteen (14) colour aerial survey films of type KODAK Aerochrome MS 2448 were processed within the project. The number of frames including those of the tie runs is approximately 4,200.

3.3 Scanning

Scanning of aerial photographs was performed prior to photogrammetric measurements. Hansa Luftbild utilised for this purpose the flatbed scanning system ZEISS SCAI. Due to its high geometric accuracy of approximately $\pm$ 2 μm, the SCAI scanner is appropriate for the conversion of aerial photos into digital images for subsequent photogrammetric processing.

The scanning device consists of a linear sensor of 5632 photosensitive elements of type CCD; the smallest possible sampling size is 7 μm. The device is determined by its capability of digitising roll film. The progression in scanning depends on the physical size of the CCD line, i.e. a standard colour aerial photograph is scanned in several swaths at 14 μm resolution within 20 minutes time.

From the aerial photographs which are flown as pin point photography, every second frame was selected for scanning and orthophoto rectification. Each of these frames covers more than the corresponding mapping unit defined by the sheet line system of Dubai Municipality (see figure 1). The original colour diapositives were scanned at 14 μm pixel size. Photographic density was transformed into RGB grey levels ranging from 0 to 255 for each channel (= 24 bit radiometric resolution). The total amount of digital data obtained by scanning is about 1.3 terabyte.

Regularly performed action after scanning was the measurement of interior orientation in the scanned images.

Figure 2: Oblique View of Part of Dubai

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

4 GEOMETRICAL FOUNDATION

4.1 Aerial Triangulation

Determination of tie points and computation of exterior orientation parameters was performed on the basis of original colour diapositives. This rather conventional AT approach had operational preference in spite of the availability of digital triangulation software MATCH-AT. The major advantage of this set-up was that productivity could be easily adapted according to demand.

Three-dimensional co-ordinates of the airborne antenna's phase centre were computed by means of SKIP software of the German firm INPHO. However, also other software, for example GPSurvey from TRIMBLE or GEONAP, a German product, is in the same way appropriate for this purpose. Standard deviation of each co-ordinate value was in the range of ± 1 decimetre.

Data processing by means of PATB-RSG was organised in blocks. The largest triangulation block covered the western part of the Dubai core area; it contains 1708 photographs at scale 1:6,500 with 9317 newly established tie points. Working at separate blocks in parallel increased the efficiency and through-put of AT activities.

Blocks of aerial photographs with GPS determined camera positions have highly favourable accuracy features since they are effectively controlled by the GPS air stations. In such densely controlled blocks there is little propagation of errors and the accuracy distribution within the block is highly uniform. Investigations during the course of this project yielded the following general accuracy potential of GPS supported aerial triangulation:

horizontal accuracy: $\approx \pm 1.5 * \sigma_0 *$ photo scale figure
vertical accuracy: $\approx \pm 3.0 * \sigma_0 *$ photo scale figure

The sigma naught value of tie points in more featureless sandy areas appeared to be larger than in regions with more detail such as the Central Business District. Standard deviation of the photo orientation angles was in the range of ± 15“ to 20“.

4.2 Digital Terrain Model

According to the Scope of Works, the Digital Terrain Model (DTM) had to be acquired by measuring regular grid points as well as irregular spot heights and natural/man-made break lines. The DTM to be delivered to the client had to be created by interpolation between these measured points at a 20 meters grid spacing, i.e. the aim is to have at hand a DTM with regular meshes of 20 meters spacing.

All height data were captured by means of stereo photogrammetric restitution utilising analytical plotters of type INTERGRAPH InterMap Analytic (IMA) and ZEISS P3/PC. Data capture was organised in MicroStation design file format (DGN files). Special attention was paid during measurement to break lines particularly at those locations where the correct portrayal of the terrain required also to register its discontinuities. This was of extreme importance at bridges and fly-overs since these are sensitive to dislocations in the final orthophoto.
The digital terrain model produced within the project was generated by means of “MGE Terrain Modeler”, a software package distributed by INTERGRAPH. A triangulated irregular network (TIN) was created from the pattern of input data. The method applied for this purpose is known as Delauney triangulation; it is a standard processing tool of MGE Terrain Modeler. The TIN structured DTM was also used for ortho-rectification since it portrays the terrain better than the 20 m regular grid.

The DTM requested by DM was created by a linear interpolation approach utilising Terrain Modeler standard software capabilities. This approach maintains as much as possible the terrain characteristics as originally determined by photogrammetric measurement of spot heights, regular distributed points and break lines. It is the most effective interpolation technique for a terrain with moderate undulation as it is mostly found in the area under survey. Height interpolation was applied by using actually measured data and not by referring to a terrain surface which was mathematically modelled.

This modelling approach would need to involve, for example, higher order polynomial equations, least squares interpolation, kriging or other more complex mathematical models which usually result in a smoothened surface of the DTM. However, even for the mountainous area of Hatta the arbitrary peaks and small irregularities of the photogrammetrically determined data were sufficiently processed by linear interpolation techniques.

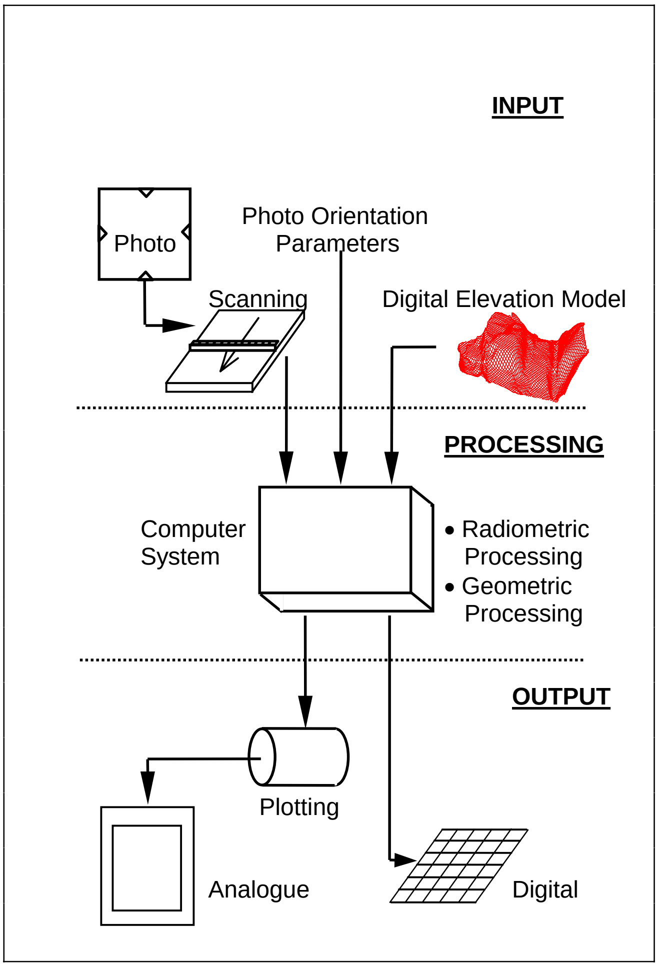


Figure 3: Process of Digital Orthophoto Production

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

5 ORTHOPHOTO PRODUCTION

5.1 Type of Orthophoto

Digital ortho-rectification transforms the central perspective of a scanned aerial photograph into an orthographic projection while eliminating influences of camera tilt as well as relief displacement on the image geometry (see figure 3). With reference to such non-pointed definitions, one can find quite often the mistaken impression that all details of an ortho-image are in their proper planimetric location; for example, the roof line of a high rise building is located exactly over its foundations. However, conventional ortho-rectification does not correct for radial displacement nor for “relief“ displacement of tall structures.

The conventional orthophoto will show the high rise building leaning radially out away from the centre of the photograph (see figure 4). This effect will become bigger the taller the building is and the closer it is to the edge of the photograph. Large scale ortho-images of urban areas may even exhibit severe distortion of buildings which are visible in particular at the seam line of adjacent photographs. Only the footprint of buildings is correct since it is usually rectified on the basis of a Digital Terrain (i.e. ground surface) Model.

The crucial point in this discussion is the quality of DTM. If in place of a Digital Terrain Model a value added Digital City Model will be used as input, ortho-rectification would permit the elimination of aforesaid distortions. The result is called a “true“ orthophoto since it exhibits even tall structures in their true location (see figure 5). However, despite the additional efforts needed to model these tall structures, there are also new effects of “smeared“ photo detail and “filling of hidden space“ which have to be treated.

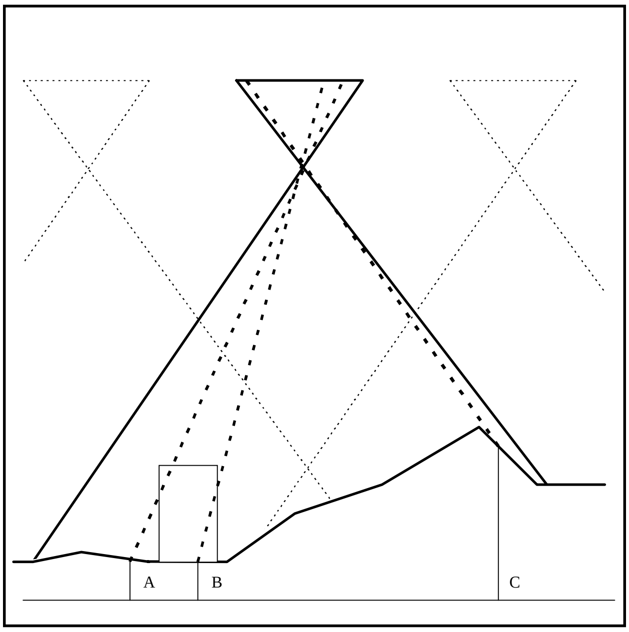
Dubai Municipality as client of Hansa Luftbild requested to have at hand conventional digital ortho-images, not true orthophotos. Nonetheless, additional efforts in creating value added DTM were undertaken by properly portraying all bridges and fly-overs. The result of this special treatment of break lines at these locations may be called a “local true orthophoto“.

5.2 Methodical Aspects

Pre-processing of the scanned image data might be useful or even compulsory for image restoration and image enhancement. This is certainly necessary if scanning is only seen as a bulk process for the conversion of aerial photographs into digital images. However, subsequent efforts in radiometric processing can be reduced if the set-up of scanning is controlled by qualified personnel.

The approach applied by Hansa Luftbild makes use of the professional experience of photographic experts. They control, for example, scanning of blocks of photographs against a master image of the same photo flight which was radiometrically treated in an optimum manner. Images within the same flight run are generally scanned using the same radiometric settings of the scanner.

Figure 4: Properties of Conventional Orthophoto



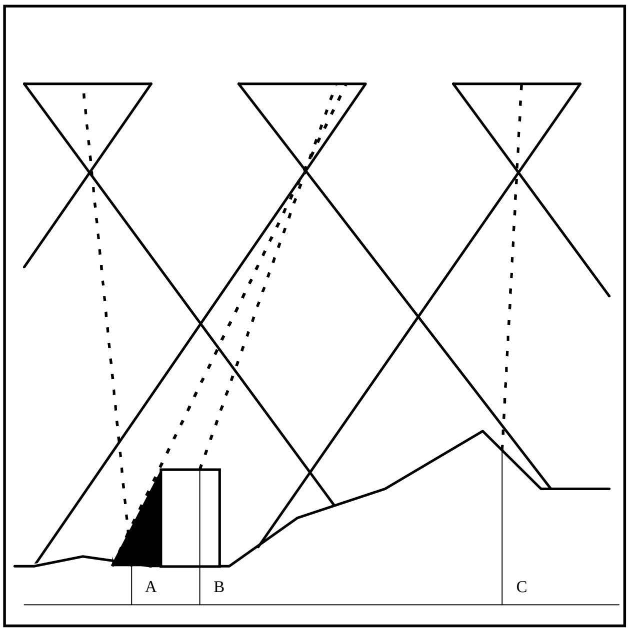


Figure 5: Properties of True Orthophoto

Nevertheless, aerial photographs are usually also effected by local variations in contrast. Most of these properties are inherent with aerial photography since variations of sun angle and different reflectance of sand and rock cause typical modulations of contrast. Even brighter and darker areas caused by illumination effects can be recognised in images of more or less homogeneous terrain reflectance. These inherent radiometric effects cannot be corrected during scanning.

Scanning and processing of a large number of aerial photographs is mainly a data management problem. A single aerial photograph scanned at 14 μm pixel size and 8 bit radiometrical resolution per spectral band results in approximately 800 megabyte of uncompressed image data.
Scanning of 1,630 standard sized colour aerial

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

photographs leads to more than 1.3 terabyte of image data that were to be handled, stored and processed during the project. It is obvious that this amount of freely available disk space is normally not present in a geo-information production environment with several competing projects running in parallel.

Intermediate storage of image data on Digital Audio Tapes (DLT), organisation of processing in harmonisation with other IT groups inside Hansa Luftbild, regular co-ordination on processing needs, preparation of batch processing during office hours and ortho-rectification-runs at night or during the weekends; these and some other ideas of data management were successfully applied for handling the actual production needs.

The mathematical approach applied for ortho-rectification within the project is founded on the collinearity equations of the central perspective; i.e. pixel by pixel. The sometimes preferred anchor point philosophy was not used. Resampling of grey values was carried out by bilinear interpolation. As result, ortho-rectification of a colour aerial photograph took on average about 2 hours of processing time. Individually applied radiometrical enhancement techniques required on average another 15 minutes operator time.

After completion of processing, the ortho-images were controlled with respect to the alignment of features at the sheet line of adjacent images and the overall radiometrical quality. Also multicolour plots on paper were produced for this purpose. At some places, the newly produced images could even be overlaid by existing but outdated vector data. This was used to control the rectification accuracy also inside the bounds of the ortho-image. Figure 6 is an example of such a composite which shows inherent dislocations caused by the perspective of tall structures as well as differences caused by building activities.

All digital orthophotos were delivered in TIFF. They were copied on 8 millimetre EXABYTE tapes. TIFF is currently considered the most common exchange format for raster data and supported by nearly all GIS products.

6 ORTHOPHOTOS AND GIS

Digital ortho-images maintain the wealth of pictorial information which is inherent in aerial photographs, and they provide in addition a geometrically corrected view from above. Mostly due to this useful twin property, the importance and benefit of digital orthophotos as an additional source for GIS is widely accepted. The combination of geometrically corrected pictorial information and object related information stored in GIS is in particular attractive for planning purposes, integrated interpretation, and reliable documentation.

However, digital orthophotos are, from our viewpoint, not simply another GIS layer, but a reference layer for a variety of applications. This is especially true for the outskirts or sub-urban areas as well as the rural areas; which are both typical target areas for planning studies.

Figure 6: Orthophoto Data of Dubai with Vector Overlay

Already existing maps of these areas, at scales ranging typically from 1:2,000 to 1:10,000, are often outdated or even founded on inadequate geometric control. Digital orthophotos provide in this case a suitable source for the control of changes, for the verification of previous data capture methods and last but not least for map revision and quality control. The geometric accuracy of previous map making can be validated when following a strategy for overall block adjustment which bridges those suspicious areas of weak geometry.

GIS data are mostly vector data; as a matter-of-course they are generalised. The degree of generalisation depends mainly on conceptual selection strategies and on the qualification of the human operators during the process of data collection. The best opportunity for verification of such interpretation and at the same time a multidisciplinary utilisation of pictorial and vector based geo-information is to merge vector data and the raster data of the digital orthophoto. Change detection, identification of action areas for planning execution or the production of affection plans on an orthophoto basis can be easily realised with this approach.

Digital orthophotos may also support typical urban survey tasks such as updating of 1:1,000 scale urban maps, incorporation of utility information into a multifunctional urban GIS, demarcation of land parcels, or verification of cadastral information.

Though ortho-images are the ideal source for planning purposes and similar tasks, it is for large scale applications to be considered that all structures protruding above the terrain are geometrically distorted in conventional ortho-images. Only those features may be extracted by on-screen digitising or similar techniques that are corrected by relief displacement, and thus features located directly on the earth surface. Despite this restriction orthophotos can successfully contribute to a substantial enrichment of urban GIS.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

Another application of GIS and photogrammetry is the three-dimensional modelling of urban areas. This kind of activity is mainly driven by the telecommunication business which is in need to find optimum antenna positions for their mobile radio networks. However, such data will also allow to generally investigate the geometric relationships in a city, and thus will contribute to special applications such as large scale city planning.

Dubai Municipality has identified the need for three-dimensional city modelling and requested that Hansa Luftbild provides the height data of each and every building in the aforementioned project area. The data were acquired by stereo photogrammetric restitution in the course of DTM measurements. The three-dimensional city model itself will be created in Dubai by merging digital map data, GIS information, DTM data and photogrammetric height measurements. Figure 7 shows a three-dimensional CAD model of a part of Dubai as anticipation of these future activities.

Three-dimensional digital city models may also be draped by building specific pictorial information, thus, rendering photo-realistic impressions. For this purpose, oblique aerial photographs or terrestrial shots of facades are digitally referenced to the geometric properties of the perspective view and wrapped around the construction. Figures 8 and 9 give the digital reconstruction of a prominent building in Dubai in photo-realistic texture viewed from two different positions (see also figure 2).

This method of utilising information and capabilities from aerial photography, GIS and CAD will open new applications for the Survey Section in fields such as city planning, construction, public work, advertisement or tourism. Also the visualisation of a planned construction embedded in a three-dimensional view of its photo-realistic environment, or the superimposition of planning studies on digital orthophotos becomes feasible.

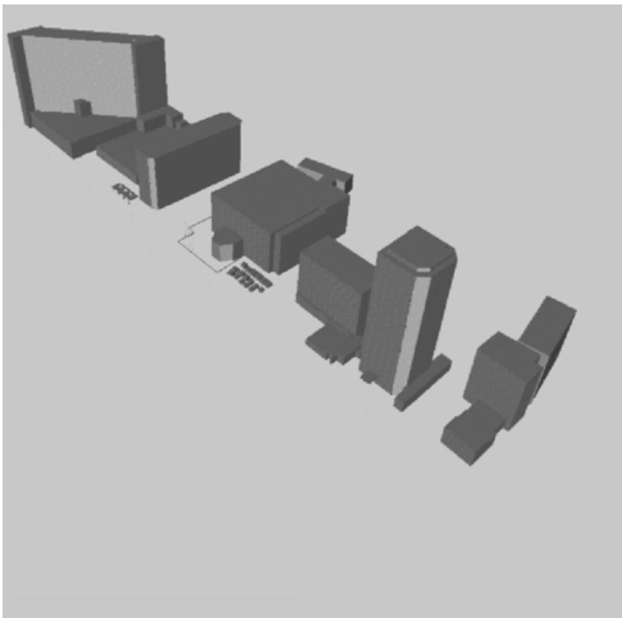
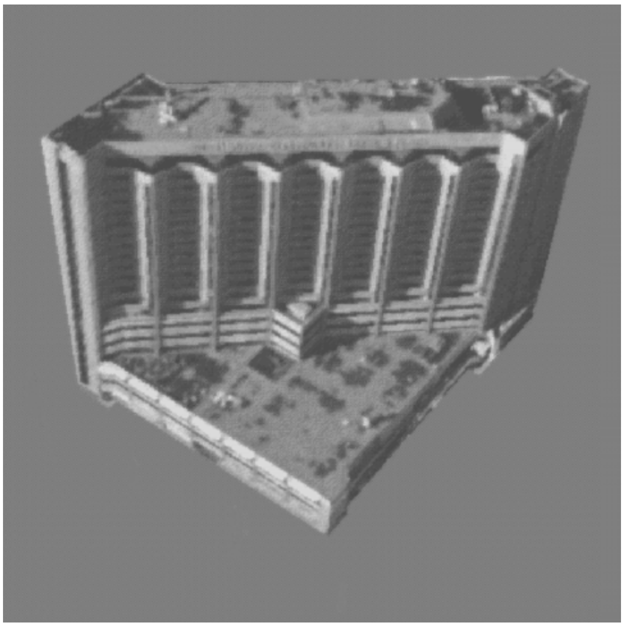


Figure 7: Perspective View of Dubai Digital City Model

Even another dimension can be added in today's practical utilisation of digital orthophotos, i.e. real three-dimensional stereo-orthophotos. These orthophoto coup-les can be actively utilised by means of GIS systems that are equipped with stereo-viewing capabilities. The necessary stereo-partner of the primary orthophoto is also known as stereomate. It can be computed on the basis of a functional model which applies the DTM to the creation of artificial x-parallaxes. Stereomates can be created easily, if necessary even for temporary use only.

The future will positively see three-dimensional object oriented GIS in which stereo-orthophotos will be an indispensable source of real world information.

Figure 8: Oblique View of Appartment Building in Dubai



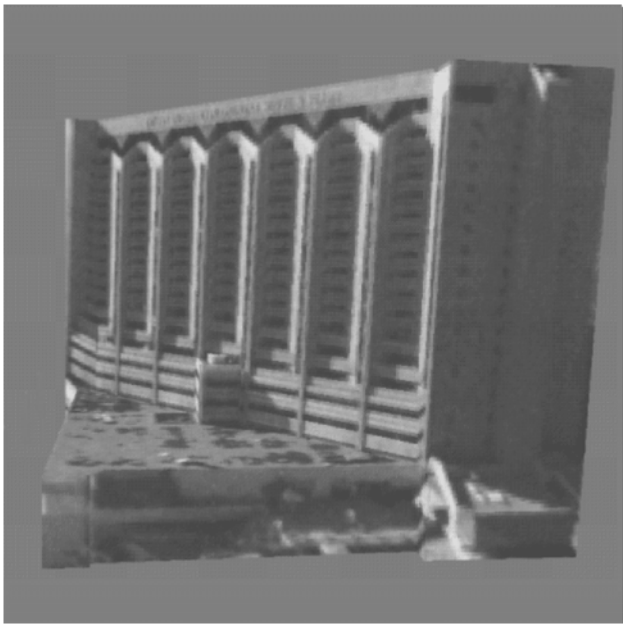


Figure 9: Side View of Appartment Building in Dubai

7 SUMMARY

Digital ortho-images provide numerous advantages compared to conventional map products, especially with respect to their actuality, their flexibility, their combination with other data sets and the creation of new products for geo-information application. Ortho-images are especially appropriate for the update of digital maps, automated mapping and the generation of new data bases. As a consequence, digital orthophotos are already widely accepted as a basic data source for digital mapping and a variety of useful GIS applications.

The production of digital orthophotos has been developed to a fully operational status utilising powerful computers, state-of-the-art photogrammetric scanning devices, and commercially available orthophoto production systems. Still a challenge, however, is managing the huge amount of data which is inherently linked with the production of digital colour orthophotos for a large project. Further improvements will be necessary in this respect to let digital orthophotos be fully accepted as a valuable source of geo-information.

One intention of this paper was to reflect on several aspects of orthophoto production within the project of Dubai Digital Ortho-Photogrammetric Mapping. It discussed furthermore an outline of possible future activities to be undertaken by Dubai Municipality in order to fully utilise their geo-information sources.

The Municipality sections for planning studies, planning execution and for surveying will definitely benefit from the still unexploited possibilities of digital orthophotos. This covers also new applications such as digital city models with photo-realistic texture mapping which were described in view of future application within the administration of Dubai Municipality.

Orthophoto data will aid the day-to-day work of planning experts. It opens furthermore the possibility to enter into new applications within the task to organise a dynamic society. The availability of these data will improve the communication between planners, citizens and decision makers, thus contributing to a wider acceptance of planning topics which are initially only actions of mental modelling.

References

Ackermann, F. (1990): Kinematic GPS Camera Positioning for Aerial Triangulation. Proceedings of the Second International Symposium on Precise Positioning with the Global Positioning System, Ottawa, pp. 1155-1168.

Ackermann, F., Schade, H. (1993): Application of GPS for Aerial Triangulation. PE&RS-Photogrammetry and Remote Sensing, Vol. 59, No. 11, pp. 1625-1632.

Amhar, F., Ecker, R. (1996): An Integrated Solution for the Problems of 3D Man-Made Objects in Digital Orthophotos. International Archives of Photogrammetry and Remote Sensing, Vol. XXXI, Part B4, pp. 84-89.

Haala, N. (1994): Detection of Buildings by Fusion of Range and Image Data. International Archives of Photogrammetry and Remote Sensing, Vol. XXX, Part 3/1, pp. 341-346.

Herms, P. (1991): Einsatz von CCNS/GPS und RMK TOP - Neue Erfahrungen und Überlegungen zur Bildflug-navigation. Proceedings of the 43rd Photogrammetric Week, Stuttgart, pp. 73-79.

Kaiser, R. (1991): The Intergraph Digital Photogrammetric Workstation. Proceedings of the 43rd Photogrammetric Week, Stuttgart, pp. 195-202.

Leberl, F., Gruber, M., Uray, P., Madritsch, F. (1994): Trade Offs in the Reconstruction and Rendering of 3D Objects. Mustererkennung 1994, Technische Universität Wien, pp. 58-73.

Roth, G. (1996): Quality Features of a State-of-the-Art, High Performance Photogrammetric Scanning System: PHODIS SC. International Archives of Photogrammetry and Remote Sensing, Vol. XXXI, Part B1, pp. 163-166.

Würländer, R., Gruber, M., Mayer, H. (1996): Photorealistic Terrain Visualization using Methods of 3D Computer Graphics and Digital Photogrammetry. International Archives of Photogrammetry and Remote Sensing, Vol.XXXI, Part B4, pp. 972-977.

Acknowledgement

The authors like to thank Mr. Eberhard Gülch for having accomplished the processing of figures # 7, 8 and 9. Dr. Gülch is employed with the Institute of Photogrammetry of the University of Bonn.