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Issues of Digital Mapping

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Abstract: The traditional role of photogrammetric restitution has been fundamentally changed by the availability of new technical developments:

Digital cameras now compete with the established technology of analog aerial cameras. A new competitor is Pictometry and Multivision for gathering images by oblique images. The production of orthophotos as substitute for vector information has proven to be more economical. The most expensive part in orthophoto generation is the creation of digital elevation models. For DEM creation alternative methods have become possible, such as radar mapping and laser scanning. Finally vector data are now not aimed at CAD products, but as topologically structured data for use in a GIS. Photogrammetric hardware and software industry is currently in the process of providing direct shapefile extraction. The aim of photogrammetric data acquisition has changed from a map orientation toward the goal to provide GIS data.

Zusammenfassung: *Zum Thema Digitale Kartierung*. Die traditionelle Verfahrensweise der photogrammetrischen Auswertung zur Herstellung von Kartenunterlagen hat sich durch neue technische Entwicklungen grundlegend verändert.

Digitale Kamerasysteme stehen heute in Konkurrenz zu den bewährten auf Film basierten Luftbildkameras. Neue Schrägaufnahmeverfahren, wie Pictometry und Multivision, stellen die Notwendigkeit der bisherigen Luftaufnahme infrage.

Die Produktion von Orthophotos als Strichkartenersatz ist weit wirtschaftlicher als die Herstellung von Vektorinformationen. Der teuerste Aspekt bei der Herstellung von Orthophotos ist die photogrammetrische Erfassung digitaler Höhenmodelle. Dafür kommen aber auch Alternativmethoden, wie die Radarabtastung und das Laserscanning infrage. Schließlich sind neuerdings die Vektorinformationen in Form von topologisch strukturierten Daten für eine Verwendung im GIS gefragt. Die photogrammetrische Geräte- und Software herstellende Industrie ist gegenwärtig dabei, die direkte Shapefile-Datenerfassung zu realisieren. Das Ziel der photogrammetrischen Datenerfassung hat sich von der Strichkartenorientierung zur Bereitstellung von GIS-Daten gewandelt.

1 Introduction

Mapping by traditional field surveys has been replaced in the 20th century using tools of aerial photogrammetry, which is now an efficiently operating, highly automated technology. But more recently during the past decade new technological aspects have been introduced to improve the mapping technology even further. Some of these trends are discussed in this paper. (see KONECNY 2003).

2 Digital Cameras versus Scanned Film Camera Images

Ever since the progress of U.S. military and that of the U.S. space program in the 1960's and 1970's digital cameras have been used to transmit images from orbits. More recently the consumer market has made a breakthrough for 5 M pixel and more digital amateur cameras.

To compete with the high level requirements of film based aerial survey cameras

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Tab. 1: Parameters of Operational Digital Aerial Cameras.

Type	no. of pixels	pixel size	ground coverage at h = 1000 m	h/b	$\sigma_{x,y}$	σ_z
Vexcel Ultracam D	7500 × 11 500	9 µm	675 m × 1035 m at f = 100 mm	3.7	+/− 9 cm	+/− 16.6 cm
Z/I Intergraph DMC	7600 × 13 824	12 µm	768 m × 1383.4 m at f = 120 mm	3.3	+/− 10 cm	+/− 16.5 cm
Leica ADS 40	12 000 lateral longitudinal 28.4° forward nadir 14.2° aft	6.5 µm staggered	swath 1924 m at h = 1540 m (15 cm groundpixels)	1.26	+/− 15 cm	+/− 20 cm

with one highly optimized wide angle objective a 900 M pixel (30 000 × 30 000) camera would be required, which is still too costly to realize, unless shortcuts are taken.

There is the option to use several lenses for imaging onto smaller CCD area array chips. This option has been realized in the Z/I Intergraph DMC with 7 lenses and the Vexcel Ultracam.

Another option is to develop the camera in form of a CCD line scanner. This option, used by satellite systems, was chosen for the Leica ADS 40 camera.

The technical details of these commercial and operational camera systems are given in table 1. (see Graham, Hinz 1999, Leberl 2005, Trinder 2005).

The imaged areas by the multilense area chips have to be resampled and fitted together according to boresight calibration information by subsequent image processing. The fitted image corresponds to resampled area arrays for a usable photogrammetric image of 7600 (longitudinal) × 13 824 (lateral) pixels for the DMC and of 7500 (longitudinal) × 11 500 (lateral) pixels for the Ultracam. Even forward motion compensation is included during image capture. These cameras are in principle independent of GPS and IMU recordings.

The radiometric resolution of digital sensor elements is by far superior (11 bit grey levels) to that of the scanned film, for which due to exposure conditions usually only 6 bit of grey level information can be retrieved for a particular exposure setting.

The same holds true for linear camera arrays. Nevertheless the resultant scanner images need to be corrected for aircraft forward motion and aircraft attitude, which are recorded by a rather expensive IMU system. It has to register the 6 orientation components in real time during the flight. Linear array camera systems therefore depend during their operation on the speed of the aircraft and its attitude changes, setting a limit to the achievable ground sampling distance, depending on the frequency at which the IMU records can be collected in form of angular differences. For that reason the ADS 40 may have difficulties to achieve the same ground sample distance for fast low level flights, as obtainable for cameras using area chips exposed at a specific time interval.

The standard flight planning procedures for analog aerial cameras need of course modifications when digital cameras are used, since the coverage on the ground depends on the chip sizes and the different focal lengths utilized for them.

The other issue is the achievable accuracy on the ground for position and elevation. Accuracy is of course a function of the ground sample size and the base-height ratio, depending not only on the lense opening angle, but also on the method of data extraction (automatic or manual). No doubt extensive accuracy tests will be made in the coming years by independent bodies to clarify the accuracy issue.

Another aspect is the product obtained by digital cameras: While cameras with area

Fig. 1: Pictometry high resolution oblique ,,Neighbourhood Image''.

arrays, after boresight calibration and preprocessing can be treated in almost the same way as analog images for aerial triangulation, DEM extraction, orthophoto generation and line mapping, the line scanner cameras more clearly depend on the processing algorithms of the manufacturers, who of course are ready to license the appropriate software packages for processing.

The digital camera technology using Canon, Kodak or Rolleimetric cameras do not quite reach the resolution and geometric accuracy requirements of the DMC, the Ultracam and the ADS 40, since they have not been specifically designed for photogrammetric mapping. Nevertheless Canon, Kodak and Rolleimetric cameras have been successfully used for mapping applications in developing countries at reduced geometric requirements. Since these cameras can be accommodated in small aircraft (Cessna, Piper) their use is possible in remote areas, for which the mobilization of a special survey aircraft is too costly.

Fig. 2: Zoom Capability to View Pictometry Oblique Images.

Pictometry View from East

Pictometry View from West

Fig. 3: View Pictometry Images from different sides with measurement capability.

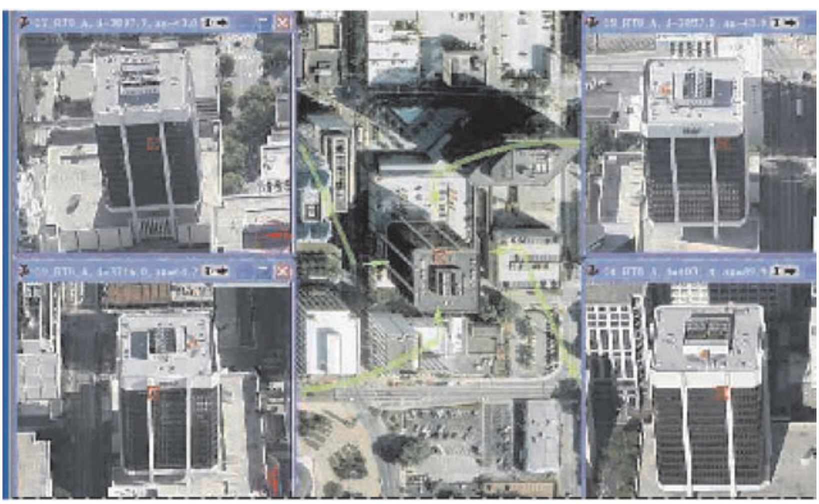

Fig. 4: Multivision Viewer with orthophoto in the center and 4 oblique images of the location in the orthophoto.

Fig. 5: 3D measurement in the Multivision oblique images.

Such cameras can, on the other hand, also be combined into camera assemblies using vertical and oblique images in up to 4 directions. These camera assemblies used by the Rochester, N.Y. based U.S. company Pictometry. The use of the Pictometry system is to enable views of all house facades of a city from oblique images and to use the 4 oblique images for linear measurements on the imaged objects (e. g. distance between two houses). The Pictometry camera systems are used from 2 flying heights producing higher resolution images from low level flights for the city core areas in form of "Neighbourhood Images", and from high level flights for the outskirts of a city in form of "Community Images" at a lower resolution. Extensive use of this technology has been made in the USA in the "Homeland Security Program" (see Figs. 1, 2 and 3 and www.pictometry.com).

In Israel Ofek-Air has produced a similar software system "Multivision", in which conventional orthophotos can be viewed and used for measurements together with separate georeferenced digital oblique images (see Figs. 4 and 5 and www.ofek-air.com). The orientation of these oblique images may be derived by space resection from the orthophotos.

Pictometry and Multivision offer the possibility to view and measure object details without the need for conventional mapping. They are therefore a serious competition in security and emergency applications.

3 Orthophoto Mapping versus Line Mapping

Traditionally line mapping was the target of the photogrammetric mapping process. Ever since the introduction of the orthophoto-rectification methodology orthophotos have been seen as map substitutes, which were faster and less expensive to produce. While a line mapping project may take years to complete, the orthophotos for the same area may be completed in one fifth of the time. Particularly in developing countries with a fast growing urban population and a lack of systematic updating systems for maps, orthophotos offer the only possibility to produce quick information for urgent needs.

Of course the cost aspect is even more important, since urban centers in developing countries can seldom afford a line mapping effort.

The costs for aerial mapping are based on the number of photos (or stereomodels) required to cover a specific area. A summary of costs of the components of an aerial photogrammetric project is given in Tab. 2. It is realized, that cost assessments are a bit risky, since market competition plays an essential role. Nevertheless the stated figures may give a relative comparison.

Mobilization for an aerial photography project is based on a fixed cost depending on the accessibility of an area, which can be high for a remote area lacking a mobilization infrastructure for operating a survey aircraft.

Scanning of photos is not required for use of digital cameras, while the costs per image, aerial triangulation, the generation of a digital elevation model, the orthophoto production and the mosaicking of orthophotos are similar for analog and digital images. However, the availability of digital cameras is still limited due to their high investment cost exceeding 1 M $.

Tab. 2: Orthophoto Mapping versus Line Mapping Costs (international average).

Process	**Remarks**	**Cost per Aerial Photo [$]**
aerial photography mobilization	constant fee per block $ 5000	–
aerial photo		10
scanning of photos		15
aerial triangulation and block adjustment		25
digital elevation model		120
digital orthophoto production		30
mosaicking of orthophotos		20
on screen digitization in 2D or 3D	rural area 10^h per image at 50 $/hr	500
	urban area 100^h per image	5000

The costs for generation of line maps using 2D procedures (for rural areas) and using 3D procedures (for urban areas) are quite high, depending on labour cost. Many mapping consortia in Europe and North America have therefore subcontracted the line mapping tasks to countries, where labour costs are still low (e. g. Eastern Europe, India and China).

Tabs. 3 and 4 compare the total cost for an urban aerial mapping project covering 250 km^2 at different GSD according to average international prices.

The total bidding prices for a mapping contract still depend on the following factors:

- production costs (as seen in Tabs. 3 and 4)
- field verification add 30 %
- overhead add 20 %
- profit add 10 %
- risks add 40 %

Tab. 3: Costs for a City Map covering 250 km^2 with 20 cm ground pixels, scanned with 15 µm from photography at image scale 1 : 13 333.

Process	**no. of photos**	**cost [$]**
aerial photography	83	4 830
scanning		1 245
aerial triangulation		2 075
DEM		9 960
digital orthophoto		2 490
mosaicking		1 660
total orthophoto cost		**22 260**
line map digitizing		124 500
total line map cost		**146 760**

Tab. 4: Costs for a City Map covering 250 km^2 with 10 cm ground pixels, scanned with 15 µm from photography at image scale 1 : 1666.

Process	**no. of photos**	**cost [$]**
aerial photography	83	7 320
scanning		4 980
aerial triangulation		8 300
DEM		39 840
digital orthophoto		9 960
matching of orthophotos		6 640
total orthophoto cost		**77 040**
line map digitizing		498 000
total line map cost		**575 040**

This is why a bid may be based on a cost plus 100% price. This may of course vary on the competitive economic situation.

When comparing pricing for a **city map 1 : 2000** produced from 20 cm ground pixels, this line map may be contracted for \$ 293 520. The **orthophoto** coverage would cost \$ 44 420.

A **city map 1 : 1000** produced from 10 cm ground pixels would be contracted for \$ 1 150 080 and the **orthophoto** for \$ 154 080.

This compares to an alternate **ground survey** procedure using GPS/DGPS and total stations at \$ 6400 per km^2 for \$ 1 600 000.

Photogrammetric mapping is still less costly than ground surveys, and orthophoto production is the most affordable procedure.

Particularly in urban areas orthophotos pose the difficulty, that the geometry of the orthophoto is based on ground elevations. Therefore the tops of buildings or bridges are displaced in the orthophoto. A solution to this problem may be the production of so called "True Orthophotos", in which the tops of the buildings or objects, produced by a digital surface model, may be shifted to obtain the true orthophoto. This, however requires manual intervention, which is costly unless automatic procedures for these orthophotos are available. The objects to be shifted must first be digitized in 3D. E. g. the company Inpho has effective software to minimize the effort in doing this. But still the costs for producing a true orthophoto may be 2 or 3 times as high as for the standard orthophoto product (see Schickler 2003).

The clients, deciding on a particular product strategy should therefore seriously consider the questions:

– What ground sample distance is ultimately needed under financial constraints (e. g. utility manholes may not be visible with 20 cm ground pixels, but utility features may be more easily determined using GPS/DGPS ground surveys. For the building topography a 20 cm ground pixel may be sufficient).
– Is it necessary to rectify roof top levels to be able to refer the orthophoto to cadastral (and most often not updated) boundary information.

4 Digital Elevation Models and Laser Scanning

From the cost comparison of photogrammetric processes it becomes clear, that one of the high cost factors is the generation of a digital elevation model by photogrammetric means (either image matching, semiautomatic grid DEM measurement or manual contouring). If a digital elevation model is already available (presumably it does not change very often) the costs for orthophoto production may therefore be significantly reduced.

This is the case, if an older contour map is digitized and interpolated into a rectangular DEM grid, which can be further interpolated for orthophoto production. Nevertheless it should also be realized, that contour maps are often generelized from maps 1 : 10 000 or smaller, and thus have a lower accuracy.

There are also alternative methods available to generate digital elevation models and digital surface models.

As has recently been shown by the Intermap Co. from Calgary, Alberta, Canada a digital elevation model with +/− 0.5 m accuracy has been generated for one third of the area of Britain (50 000 km^2) and with +/− 1 m accuracy for the additional area of two thirds of Britain (100 000 km^2) with 5 m posting at a cost of 6 \$/km^2 per customer with the Star-3i airborne radar in the "Nextmap Britain" project.

Satellite radar systems, such as those flown on the Space Shuttle Radar Topographic Mission (SRTM) provided a nearly worldwide DEM at 90 m posting with +/− 5 m accuracy in areas not affected by radar shadows and layover in mountain areas. For the U.S. the posting of the data has been reduced to 30 m. Even though the posting and the accuracy is still rather low, the information may be utilized with near vertical high resolution satellite images (Quickbird, Ikonos) to produce digital satellite image orthophotos of 2 to 3 m accuracy, if near vertical images are used. Also Google Earth makes use of the information for viewing (see HENDERSON 1998).

Another technology is airborne LIDAR. At present about 140 Lidar systems operate worldwide (most of them are made by Optech, Leica and TopEye). Newer LIDAR systems operating at 100 KHz pulses are able to generate digital surface models (first pulse return), digital elevation models (last pulse return) and intensity images.

Depending on the flying height ranging between 100 m and 6000 m submeter to 10 m postings may be generated with dm to m accuracy (see ACKERMANN 1999 and BALTSAVIAS 1999).

The problems with LIDAR data are caused by the fact, that the GPS/DGPS Continuously Operating Reference Systems (CORS) and the IMU data are generally not timed accurately enough with respect to the more rapid laser pulses. Furthermore the identification of ground points in the laser image is not as accurate as in optical images.

Therefore cross flights must be used to mosaic the laser images. To geocode them the use of elevated targets is the best practical solution. In the future the simultaneous operation combined with optical digital cameras is expected.

5 CAD Mapping versus GIS Shapefile Mapping

Most digital mapping efforts have in the past served automated map production in form of Autocad or Microstation files. With these a great number of feature codes have been used with annotated symbology added to the graphics, which does not have relational intelligence.

As mapping must now be considered as a base for the analysis capabilities of a GIS, there is the need to adapt the photogrammetric data acquisition into an object orient-

Fig. 6: Vector Graphics with Label Points.

ed data structure. As GIS shapefiles carry the data topology and give access to attribute data entries into object relational databases, photogrammetric data acquisition should use these advantages (see Figs. 6 and 7).

There were early attempts for this type of data acquisition in Zeiss Phocus and in Wild System 9.

For new data acquisition several hardware/software manufacturers now provide or attempt to provide practical solutions for direct shapefile creation during the 3D digitisation process in digital photogrammetric work stations:

– Inpho-DATM
– KLT
– Leica LPS
– Socet Set 3D
– Z/I Intergraph

As many mapping companies already own efficient workstation software, e. g. the Microstation based Z/I Image station software, or the use of Bentley''s Geographics, the alternative to the direct solution is the conversion of Microstation or Autocad data into shape files, even though this is not a fully automated process.

While the topology required can be generated automatically into shapefiles for most of the features, the intelligence must be entered manually into attributes attached to label points.

This will help to reduce the required number of feature codes, which in any case are impractical to update.

This semiautomatic conversion procedure is in any case required for already collected datasets in Microstation or Autocad files.

The GIS concept, as demonstrated in the ESRI ArcGIS platform, clearly aims at the generation of an updatable object oriented geodatabase solution. Photogrammetric Operations must now be aimed toward this goal.

Fig. 7: Shapefile Map.

The advantage of a proper geodatabase design lies in the possibility to separate point coordinate information for specific points (e. g. boundary points) from topologically related line and area information. This permits to generate the topology of land parcels, buildings and other objects, regardless of the accuracy with which the nodes (boundary points) have been determined. It is therefore possible to use rather low resolution ortho-images with ground pixel sizes ranging from 20 cm to 2 m to create the object topology first, and to improve the point coordinates in a sporadic manner by DGPS ground surveys, when the need arises in transactions.

The object relational database attributes attached to points, line segments, areas and defined objects are the basis for GIS analysis.

6 Conclusions

The present state of technological development in photogrammetry is marked by a transition from an established, but isolated and self sufficient mapping technology into a GIS integration concept. The product is not a map any more, but base data within a GIS.

Analog aerial camera technology is gradually replaced by digital camera technology. Cost effective GIS products, such as orthophotos contained in a geodatabase in raster form are combined with vector data in superposition. A combination of survey methods ranging from terrestrial DGPS uses for certain features to 3D photogrammetric data acquisition and laser scanning offers a cost optimised approach for new mapping or its updating.

Finally, the GIS data base concepts should be the guidelines along which photogrammetric products should be developed. Photogrammetry is presented with a new challenge by these developments.

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