Digital Photogrammetry Joins GIS - A Powerful Combination

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Abstract

This paper reports on the combination of Digital Photogrammetry and Geographic-Information-Systems. Traditionally photogrammetry delivers three-dimensional world coordinates. GIS, however, administers in most cases two-dimensional world coordinates and stores the elevation of an object as its attribute. The rapid progress in the technological field of digital photogrammetry over the last few years has made available all classical, basic tasks of photogrammetry. These are aerotriangulation, the generation of digital terrain models, orthoprojection, and, last but not least, three-dimensional data acquisition in stereo plotters. All these functionalities are available in digital form, i.e. on the workstations which are the home of GIS. As both technologies deal to a vast extent with coordinates, it appears natural to combine the two. In doing so DP contributes its expertise in handling huge raster images and performing 3D-data capture, while GIS contributes its expertise in handling non-topographic data and managing data bases. Integrating DP in GIS is mainly based on DP's capability of forming automatic measuring procedures. In this paper special focus is put on the usage of DP in GIS for the purposes of 3D-data acquisition, 3D-visualisation. The potential 3D-manipulation of 2D-GIS-data by using a digital stereoplotter shall also be discussed in more detail.

1 Introduction

Geographic information systems (GIS) are in widespread use in urban planning departments, and in traffic management, telecommunications and utility companies among many others. The ever increasing use of GIS also causes a significant increase in requests for detailed information which has to be gathered and kept up-to-date. More powerful personal computers and workstations allow for the processing of data bases of ever increasing size. This again forces the requests to GIS to increase. This acts like a spiral where GIS keeps constantly moving faster. The requests focus especially on the administration of more detailed data, more precise reports, faster availability of results, and better visualisation tools for presentations.

GIS is not yet as much developed to administer true 3D-data as it is for 2D-data. For more detailed information the third dimension, i.e. the elevation, has to be introduced as an integral part of the geometric definition of an edge by using its coordinates. In almost all GIS today this is achieved by assigning the elevation as an attribute to the object of interest. As can be seen in the more recent literature (e.g. Kraus 1991, 1995, Reinhardt 1991, Carosio 1995, Fritsch 1995, Kophstahl 1995) there is an ongoing discussion on the efficient treatment of true 3D-data in a true 3D-GIS. It is, however, without doubt that photogrammetry is ideally suited to do topographic 3D data capture.

So far 3D data has been captured at analytical stereo plotters which were equipped with data acquisition systems tailored for photogrammetry. Since the technology of *Digital Photogrammetry* (DP) constantly gains in relevance it appears necessary to join DP with GIS. Up to now the results of photogrammetry which are e.g. orthophotos and digital terrain models (DTM) have been used by GIS to a certain extent. This paper focusses on some of the potential DP-data-acquisition capabilities and their integration in GIS. The D-system PHODIS of Carl Zeiss is used as ,an example for this integration.

In the following, an overview of today's digital photogrammetry is presented. There follows a chapter on GIS and DP in which the special functions of DP for GIS are discussed. Finally, the concluding chapter summarizes this paper and gives an outlook.

2 Digital Photogrammetry

Digital photogrammetry can now perform all basic photogrammetric tasks. Besides the scanning of aerial images which is a pre-requisite of DP, *digital and automatic* aerotriangulation, the automatic generation of DTMs, digital orthoprojection, and, last but not least, 3D data acquisition on digital stereoplotters are now applied in production environments. This availability of basic photogrammetric functionality is considered as *phase I* of DP. The applications are complete as can be seen in table 1 for the PHODIS family of products for DP. An important design property of software based DP is the high modularity of single products and their components. This allows for a high „recycling" value which in turn eases the task of integrating DP in other systems, e.g. GIS.

Product	Photogrammetric Application
PHODIS SC	photogrammetric scanning
PHODIS AT	automated digital aerial triangulation
PHODIS ST	digital stereoplotting
PHODIS TS	automatic DTM generation
PHODIS OP	digital orthoprojection
PHODIS M	monoplotting
PHODIS Base	basic DP tools

Table 1: PHODIS products and applications overview

SCAI is the name of the scanner module in PHODIS. It has the capability to handle uncut original roll film. It is integrated into the PHODIS SC scanning system. The availability of the roll film autowinder is an important step towards automating the A/D conversion of large amounts of analog imagery (Mehlo 1995, Roth 1996). Roll films can be automatically digitized without having the requirements to cut the original negatives on the film roll. The scanning can take place in unattended mode. The modular design of SCAI allows its connection to various workstations. Scanning does not require special photogrammetric knowledge and so can be done by non-photogrammetrists.

The digital and automatic aerial triangulation is the youngest member in the family of DP-applications (Mayr 1995, Braun et al. 1996). It is basically possible to fully automatically tie together blocks of images of any constellation and number of images. This triangulation task is covered by PHODIS AT. Sub-dividing in more convenient sub-block sizes is available. Amongst other topics, special attention was paid in PHODIS AT to interactive block preparation, the overall user interface, and the correlation-based ground control point measurement capabilities.

The automatic generation of DTMs has been in daily use for several years. In order to improve this process, a special user interface was added. PHODIS TS (Dörstel 1995) expands the DTM matching capabilities with stereoscopic superimposition of the derived DTM and interactive DTM editing.

Digital orthoprojection helped introduce DP sucessfully. Digital orthophotos are imported into GIS and as such form the basis of a hybrid data capture method which is called *on-screen digitizing*. In addition to digital orthophotos, called orthoimages, PHODIS OP also delivers radiometrically balanced mosaics of orthoimages.

The functionalities of a digital stereoplotter as a 3D-digitizer are explained in more detail in the next chapter. Special emphasis is placed on those properties which are, from the point of view of the authors, of particular relevance to GIS. More literature on the PHODIS ST digital stereoplotter is found in (Dörstel and Willkomm 1994, Dörstel 1995).

Monoplotting or *on-screen digitizing* has been practiced in photogrammetry and GIS for some time. It allows data acquisition by means of digitizing on top of an orthoimage which possesses a simple relation to the world cordinate system, e.g. UTM. The orthoimage is then said to be *geo-referenced*. Geo-referenced topographic data sets can be superimposed on orthoimages and be reviewed e.g. for changes, in an interactive manner. GIS with *on-screen digitizing* capabilities is called *hybrid GIS* since, as well as general purpose information and vector data, the GIS now also deals with the raster data set of the orthoimage. If a DTM is available and in geo-reference to the orthoimage then a hybrid GIS can generate and store on-line an elevation for every planimetrically determined location as a function of its easting and northing coordinates.

In addition to all of above mentioned functionalities DP offers the application of automated measurement procedures. Examples of such are the fully automatic restoration of the interior orientation of an aerial image (AIO), see (Schickler and Poth 1996), or the fully automatic measurement of conjugate image points in order to derive the parameters of the relative orientation (ARO), see (Tang et al. 1996). Such modules are essential intrinsic components of the photogrammetric basis of DP and thus part of PHODIS Base which acts as a server to the applications on top of it. Open interfaces for data exchange and programming allow users and developers to communicate with different software packages. This property is used in the combination of DP with GIS.

3 GIS and Digital Photogrammetry

Topographic data acquisition is gaining in importance for GIS. It is well understood that data acquisition is the most cost effective part of running GIS. Therefore it can be accepted for economic reasons to integrate photogrammetric data capture principles when it comes to the modelling of topography in GIS. This is valid if the usage of such a data acquisition system is reliable and efficient for the GIS-user. Another important issue for GIS is that by using DP, available remotely-sensed data can be processed geometrically. DP takes care of the specific geometry models underlying various remote sensing satellites which may produce images in the visible and / or invisible wave spectrum.

This paper deals with aspects of topographic data acquisition in and for GIS. It especially concentrates on 3D-data acquisition. So far topographic 3D-data were compiled primarily on analytical stereo plotters. These were equipped with data capture software especially tailored towards the requirements of the photogrammetric community. Data were transferred via translator programs from photogrammetric data bases to the GIS data base. This process caused expensive time consumption and sometimes also loss of information. In order to perform 3D-data acquisition easier and more efficiently it appears natural to apply GIS itself for the topographic data acquisition task. Missing photogrammetric functionalities e.g. rectangular closing of houses, compilation of parallel lines by either digitzizing or by automatic line following, or the automatic extraction of houses will be thrown in by DP as selectable modules.

In the 2D-domain GIS already is used for interactive *on-screen digitizing* in e.g. ATKIS (Dasing 1995, Kophstahl 1995). Automating this area is still in the research field (e.g. Heipke et al. 1994, Englisch 1995, Mayer 1995). Approaches have been made in *semi-automatic* and *automatic* data acquisition. An example of this is the line following process in large scale orthophotos. The preferred procedure is the *semi-automatic* one (Englisch 1995, Mayer 1995) which appeares to deliver more reliable results in practical tests. It is interesting that these algorithms work on underlying orthoimages. These offer the geo-reference in an easy way. *Semi-automatic* procedures require interaction with the user who, for example, sets the starting points of a variety of processes for extracting houses or line following. These processes are then invoked. They in turn will guide the user to all houses and lines found for the purposes of validity checking and / or entry of additional information needed to continue. Such a procedure has at least two advantages. Number one advantage is the fact that the user does not have to digitize all objects of interest himself. The DP-system takes over the measurement part of this task. Only the identification of the objects to be measured has to done by the user. Number two advantage is that the measurements are objective measurements.

The expansion of existing GIS to the third dimension has been done mostly by attaching a DTM to the GIS. In order to fully integrate the third dimension, some people (e.g. Pilouk and Kutouiyi 1994, Kraus 1995) propose the use of *vertical data bases*. These appear to guarantee the topology of the data and guarantee unambiguity of data also in the vertical direction. In general unambiguity is a constraint for 3D-data in GIS.

When the GIS is used directly as the data acquisition system, data transfers from the photogrammetric data base to the data base of GIS disappear. This eliminates in an elegant way the time consumption for running translators and avoids eventual losses of information.

From today's point of view a digital stereo plotter is for GIS the ideal system to acquire 3D-data. Besides the floating mark control device there is no special hardware required. GIS and the digital stereo plotter can be implemented on one and the same computer. These are very good starting positions to join GIS and DP closely.

PHODIS ST is the digital stereoplotter within the PHODIS product family. It contains a modular and open programming interface which already is used by the PHOCUS, CADMAP, and MicroStation™-based CADMAP/dgn mapping packages. AIO and ARO are standard components of PHODIS ST. The interactive measurement of ground control points is supported by matching procedures which deliver accuracies of up to one tenth of a pixel size. This fulfills photogrammetric accuracy requirements. The user can apply in all important image orientation steps easy-to-learn automatic program modules. Every single module can be integrated into a GIS on request. In addition to the orientation steps PHODIS ST also administers an arbitrary number of stereo models per project. The main purpose of PHODIS ST is stereoscopic display in order to be able to acquire metric 3D-data and to superimpose 3D-data. The digital stereo plotter described above represents a *raw stereo device* which finally becomes a stereo plotter when connected to a 3D-data acqisition system. A more detailed description of PHODIS ST can be found in (Dörsel 1995).

The *raw stereo device* in PHODIS ST possesses special functionalities which make its usage as a 3D-digitizer for GIS attractive. These are the *on-line Z-correlation*, *draping*, and *superimposition in transparent mode*. These properties will be presented in the following chapters.

3.1 On-line Z-correlation

Initially the floating mark is set to ground in an oriented stereo model. After activating the measuring mode of on-line Z-correlation the Z-wheel can be switched off. Changing the position of the floating mark in object space by moving the floating mark control device, which in PHODIS ST is called the *P-mouse*, contributes one part to the movement of the floating mark in the image space. The remaining part of the image space movement of the floating mark is caused by the result of the Z-correlation. The implemented algorithm is based on an adopted and optimized image matching process.

It is possible that an individual can measure in stereo without the requirement to also see stereo. This apparent paradox is called *OneEyeStereo* and is also the name of the on-line Z-correlation proprietory to PHODIS ST. *OneEyeStereo* is implemented as a robust algorithm. It can distinguish between three states. These are *good correlation*, *acceptable correlation* and *no correlation*. The correlation results can be visualized on-line as colored floating marks. Such an approach can be compared to the states of a traffic light. It cannot be guaranteed that *OneEyeStereo* always will deliver *good* or *acceptable* correlation results. For this reason it is necesary that the user is be able to see stereo and capable of using the *P-mouse*.

OneEyeStereo can be used in two different modes, as of now. The first operating mode is called *move and correlate*. The user drives to an arbitrary point and switches on-line Z-correlation on. The second mode allows continous correlation and registration of XYZ where the coordinate triple may be accompnied by the attibute *good*, *acceptable*, or *no correlation*. *OneEyeStereo* is integrated in the *raw stereo device* of PHODIS ST. Hence it is available to any connected 3D-data acquisition system. For GIS-users this represents an important improvement towards easier 3D-measurements. The previously required capability of the operator to see stereo is greatly reduced.

3.2 Draping

Draping is the capability to visualize 2D-data in a stereoscopically correct superimposition. In order to achieve this photogrammetric paradox a DTM is assigned to the stereo model. All 2D-data, i.e. eastings and northings, are used as arguments for the interpolation of the corresponding elevations. The 2D-data are thus *draped* over the DTM. Using this functionality, any 2D-data sets can be stereoscopically visualized. The accuracy of the stereoscopic superimposition, however, is dependent on the quality of the DTM and, to a much lesser extent, on the quality of the model orientation. Usually orientation parameters are correct as otherwise there would not be a stereo model. As some GIS consider the DTM an external data set it is easy to connect it to the *raw stereo device*. There is a generic DTM interface built into PHODIS ST which defines the general DTM data access. Basically any DTM data can be connected this way to the digital stereoplotter. Draping allows simple and efficient DTM checking. The planimetric coordinates of a point are used as arguments for the Z-interpolation, Z_{DGM}. At the same time the floating mark can be set on the ground, either manually or by means of *OneEyeStereo* and one obtains $Z_{measured}$. The difference $Z_{diff} = Z_{measured} - Z_{DGM}$. gives a measure of the quality of the DTM. In GIS this can be applied to assess the quality of a DTM by checking single points and evaluating all Z_{diff}.

3.3 Superimposition in transparent mode

When visualizing defined areas in GIS often these areas are covered in a transparent mode. This emphasises a particular area, for example with a colored tint, but still lets the image contents of this area be seen through the overlay. This technique is known from thematic cartography. Such a visualisation mode puts a tremendous amount of graphics performance on a digital stereoplotter.

4 Conclusions and outlook

The achieved technical status quo in DP forms a solid position for introducing DP as a technology to be applied by GIS for 3D-data acquisition. The reasons for this are more than that DP is implemented on the same computer hardware as is GIS. In particular, the automatic procedures, like AIO, ARO, semi-automatic GCP measurements, *OneEyeStereo*, and Draping, are the functionalities which give the photogrammetrically unskilled GIS user access to 3D-data acquisition and let him still use and stereoscopically superimpose his 2D-data sets. Photogrammetric tasks like interior, relative, and absolute orientations are either fully- or partly automated. Three-dimensional measuring is separated into an interactive identification step and an automatic determination of the coordinates. The combination of 2D-data with available DTM-data enables the stereoscopic superimposition of existing 2D-GIS-data-sets. This can be used e.g. to check the topographic part of a GIS data base for completeness by superimposing it over the stereo model. This makes data base updating both easier and faster. Increasing demands in the quality of data make the elevation a necessary component in GIS. However, in order to represent and administer true 3D-coordinates and geometric 3D-structures in a GIS data base correctly the GIS data base definition has to be modified and improved.

DP offers GIS the potential to integrate 3D-data acquisition. Object oriented GIS and DP-systems will offer an even better base for the combination of GIS and DP. This will extend GIS' capabilities significantly and makes it a P-GIS (Photogrammetry-GIS or Power-GIS). GIS will maintain its existing capabilities and can access through DP additional data capturing principles which also can be applied to remotely sensed data

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