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Automated Photogrammetry with PHODIS®

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ABSTRACT

This paper describes the PHODIS components and, in particular, deals with the high degree of automation implemented in this system. PHODIS AT is used as an example to demonstrate the remarkable cost-effectiveness offered by digital photogrammetry with PHODIS. The concept of Integrated Digital Photogrammetry (IDP) is then presented. IDP is synonymous with the future-oriented approach to photogrammetry at Carl Zeiss.

1. INTRODUCTION

Commercial, digital photogrammetric systems have been on the market for several years now. The first components offered were modules for orthophoto production, which were soon followed by digital stereoplotters. Subsequently, the first systems for automatic digital DTM generation became available. The most recent additions on the market were systems permitting automatic aerotriangulation. Automation has been introduced step by step in digital photogrammetry, but the scope of its capabilities is still far from being fully utilized. The suppliers of photogrammetric systems initially designed digital plotting systems by copying analytical plotters and increasingly implementing automatic measuring techniques. It is only now that systems which make full use of the capabilities of digital technology are being launched on the market. The processes of scanning, aerotriangulation measurement, DTM measurement and orthophoto generation can already be largely automated. Only fully automatic "feature extraction" is not yet suitable for practical application at this stage. It should be mentioned however, that an increasing number of interactive approaches exist and will soon be integrated into photogrammetric systems. Although ongoing automation will not make the operator superfluous, his responsibilities will change significantly: his future work with the systems will primarily consist of interpretation and monitoring. The operator will remain indispensable, for example, to support the automatic processes in building and road measurement whenever complex objects can no longer be automatically recognized. But even in open terrain corrective intervention by the operator will continue to be necessary.

PHODIS is the digital photogrammetric system from Carl Zeiss which has been very successful since its launch on the market in 1991. PHODIS initially comprised an orthophoto module and was very rapidly extended by a stereo- and monoplotter, TopoSurf and finally by the automatic aerotriangulation system and a roll film scanner. These PHODIS components will be dealt with in the following chapters, with special emphasis on the degree of automation already achieved. Finally, an outline will be given of how PHODIS will be expanded in the future.

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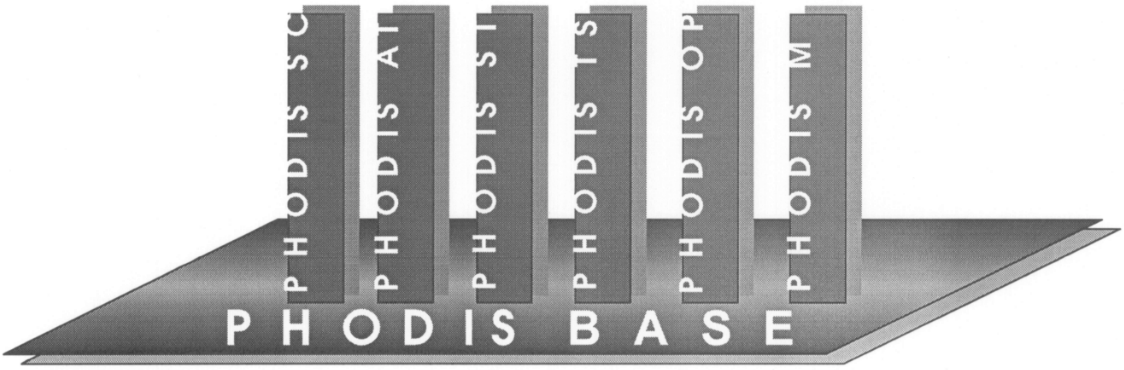
2. PHODIS COMPONENTS



2.1 PHODIS SC (Automated Scanning)

State-of-the-art, high-performance photogrammetric scanners permit the processing of uncut roll film. This opens up a host of new automation possibilities in the scanning process. The SCAI® scanner from Carl Zeiss, which processes uncut roll film, is the current benchmark system for photogrammetric scanners (Mehlo, 1995; Roth, 1996). The PHODIS SC scan software permits the digitization of roll film in the batch mode in overnight operation. The start of each photo is automatically determined; gaps in the photo sequence are automatically recognized and skipped. Pyramids can be computed for the images, and the interior orientation data can be called fully automatically. In addition, a user-defined procedure can be assigned to each scanning process, permitting e.g. the immediate archiving of the images or their distribution to other hard disks or computers via the network. SCAI scans approx. 10 color photos with a resolution of 28 µm per hour. New functions in PHODIS SC will further reduce the necessity of interactive operations for the determination of setting parameters in the future.

2.2 PHODIS AT (Automated Aerotriangulation)

PHODIS AT makes full use of the benefits of digital photogrammetry and speeds up the aerotriangulation process many times over. Starting out from rough information on the block structure, a combined "feature based" and "intensity based" matching method is used for the fully automatic measurement of all tie points in the block. In this process, the points are simultaneously measured in all overlapping images. Automation in PHODIS AT has advanced to such a degree that the operator only needs to monitor the process and perform the semi-automatic measurement of the control points. PHODIS AT offers the following outstanding features:

- Block information can be imported from the flight management reports. If no reports are available, the block information can also be specified in a local system.
- The block can be divided into subblocks to solve the problem of limited disk capacity.
- Simultaneous "multi-image" processing, i.e. the simultaneous matching of images with multiple overlaps.
- Semi-automatic control point measurement
- Fully automatic tie point measurement
- Convenient user guidance
- Processing of any type of block configuration combining longitudinal and crossing strips

- Connection to standard block adjustment programs such as PAT-B, BINGO, BLUH, ALBANY, CLIC
- Fully automatic generation of control point sketches.
- No need for GPS or DTM data which are required in some other systems.

The extraordinary cost-effectiveness of the system and, in particular, the high attainable accuracy have been verified in intensive tests (Hartfiel, 1997; Braun et al., 1996). The largest coherent block measured until now displays the following characteristic data:

- 1200 images (black and white) comprising 16 normal and 4 crossing strips
- scanned at 28 µm (PHODIS SC with SCAI)
- area: Rocky Mountains near Denver with pronounced differences in elevation (> 1000 m)
- storage capacity approx. 120 GB
- 21 ground control points

The tying of the complete block was achieved within a computation time of 137 hours. The subsequent robust block adjustment was performed without any problems (the last PAT-B run took as little as 19 minutes). A total of some 440000 measurements were carried out fully automatically. The block adjustment provided a σ_0 value of approx. 3.2 µm. The computation time of 137 hours for tie point measurement and the additional fact that PHODIS AT only requires a negligible block preparation time clearly testify to the high cost-effectiveness of the system.

2.3 PHODIS TS (Automated DTM generation)

DTM generation was one of the first applications in Digital Photogrammetry to become highly automated for operational production-oriented photogrammetry. As the generated DTMs require some means of quality control, interactive tools have been developed to check, re-measure, and substitute the automatically derived elevations by interactive measurements. Tools of this type have been implemented in PHODIS TS which incorporates the functionality of a digital stereoplotter (see below). In preparation for an automated DTM run, morphological information such as breaklines, cut-out areas and singular points can be collected in the stereo model. This additional information helps to further increase the quality of the automatically measured, derived, and modeled DTM which is optimally generated for the stereo model. Stereoscopic color superimposition of the resulting DTM and secondary data, e.g. contour lines, is possible. Thus, DTM generation is partly an interactive and partly an automated processing stage in the photogrammetric production flow.

2.4 PHODIS OP (Orthoimage Generation)

Orthoimages are digital orthophotos. Their generation, in the way implemented by PHODIS OP, is often the main purpose of a photogrammetric application flow. Aerotriangulation and DTM generation are then considered as necessary, but only intermediate steps. Fortunately enough, all three applications - aerotriangulation, DTM generation and orthoimage generation - are extremely suitable for automation. Geometrically ideal orthoimages can be obtained by digital orthoprojection if artificial objects such as houses, bridges etc. can be modeled (Mayr 1994). Such objects can then be correctly positioned within the orthoimage. In this way, the orthoimage achieves a level of quality that can never be reached in an orthophoto produced, for example, on an analytical orthoprojector. Also of importance is the possibility of generating radiometrically homogeneous, seamless orthoimage mosaics. Both, orthoimages and mosaics, often serve as an image backdrop for the vector information stored in the GIS data base.

2.5 PHODIS ST (Digital Stereoplotting)

Digital stereoplotting has to compete with analytical stereoplotting. To achieve the same performance, it must be possible to move large image windows smoothly in a continuous stereo mode over the stereo monitor. All implementations used an intermediate preprocessing step and generated pairs of epipolar images. This reduced the display task to a simple translation of the image windows. The drawback, however, was the preprocessing step which required disk space and extra time. With PHODIS ST10, Carl Zeiss for the first time introduced the stereoscopic display of a pair of oriented images without the need to generate epipolar images in an off-line preprocessing step. This is possible through an algorithm which acts as a kind of *digital real-time dove prism* and also allows continuous zooming, real-time image rotation, and arbitrary image positioning with subpixel accuracy and with on-line resampling in real-time. The equivalent of the real-time loop known from analytical stereoplotters is open, e.g. for the implementation of different imaging geometry’s. This feature has been incorporated to integrate the imaging models of the SPOT and MOMS cameras in a mathematically correct way (Dörstel, 1996). An application programmer's interface enables PHODIS ST to be hooked up to different data acquisition systems. This is of particular interest for GIS which in this way can consider the digital stereo plotter as a 3D-digitizer and directly record 3D coordinates and topology. Such automated orientation procedures as automatic interior and relative orientation have successfully simplified the stereo model setup and made it attractive, for example, for GIS users.
For full utilization of the nature of digital photogrammetric images, knowledge of the stereo pair geometry is essential. High-performance image matching strategies now enable reliable real-time Z-correlation. The conditionally combined matching algorithms applied are based on an optimized Least Squares Matching approach. It provides an evaluated, reliable matching result several times a second. This powerful method now available permits guidance of the floating mark in one image while positioning the stereomate correctly in elevation at the same time. The stereo impression is automatically maintained. As there is no need for stereo viewing to measure 3D coordinates, the verbal paradoxon *OneEyeStereo*® was selected to name this process. It becomes a standard feature in PHODIS ST10.

2.6 PHODIS M (Digital Monoplotting)

The combination of orthoimages or mosaics with a DTM and their use for coordinate measurement is the classical task of monoplotting. PHODIS M implements this combination and the connection to either PHOCUS or MicroStation. Map revision, map updating, and change detection are examples of applications for which this tool can be used.

2.7 PHODIS Base

PHODIS Base forms the basis of the dedicated PHODIS components. It provides all functions jointly required by the PHODIS components and, in addition, offers each user a software interface to permit the control of PHODIS components or the processing of PHODIS data files via user-specific software. PHODIS usually receives its digital images from the Zeiss SCAI or PS1 scanner, but it also processes images from other scanners in different formats which are converted into PHODIS image files by PHODIS Base. One of the largely automated modules of PHODIS Base is the interior orientation feature (AIO) which permits fully automatic measurement of the interior orientation for all common types of aerial survey camera. AIO determines the position of the fiducials and the image rotation, and is able to recognize whether the image is a positive or negative and whether a "right reading" or "wrong reading" image is involved.

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3. INTEGRATED DIGITAL PHOTOGRAMMETRY (IDP)

IDP is a synonym for a future-oriented approach to photogrammetry from Carl Zeiss. IDP combines the following goals:

- Product-related thinking
- Highly automated production processes
- High productivity and cost-effectiveness
- Block-based approach
- Use of various sensor models
- Simple, intuitive user guidance

In the following, these keywords are explained in more detail.

3.1 Product-related Thinking

Classical digital photogrammetry usually deals with the following products:

- scanned photos (raw digital images)
- orientation (interior, exterior, relative and absolute)
- digital terrain models (DTM)
- orthophotos and orthophoto maps
- digital vector data incorporated into GIS and CAD/CAM systems for the derivation of maps.

Until now, photogrammetric systems have generally been designed in such a way that the customer needs to know which steps are required in what order to obtain a specific final product. IDP now adopts a different approach. It incorporates the philosophy that the operator specifies the product to be generated and is then guided in the process by PHODIS. Processes suitable for automation are performed automatically, whereas interactive operator intervention is required for others. At intervals, the operator is requested to confirm the intermediate results of the automatic processes before new automatic processes are started. The product-related approach will be gradually implemented in PHODIS. This could be achieved in the following steps:

- Analysis of the current status and information on the processes required to generate a product.
- Implementation of work cycles which can be either predefined or automatically generated.
- Implementation of assistants as they are known from the PC world.

3.2 Highly Automated Production Processes

PHODIS AT and PHODIS SC have demonstrated that production processes can be automated to a large extent. In PHODIS AT, for example, operator intervention is only necessary for the control of the program system, semi-automatic control point measurement and block adjustment. It is now intended to utilize the excellent experience gained with PHODIS AT for the other PHODIS components in order to promote the IDP approach. The logical starting point for the implementation was PHODIS OP.
One of the features to be integrated into IDP is automatic object recognition. It will certainly take a few more years for fully automatic object recognition to reach a stage suitable for use in photogrammetric systems. Various promising semi-automatic techniques already available today still need to be adapted to practical requirements.

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3.3 High Productivity and Cost-Effectiveness

After one year of practical application, it can be said that PHODIS AT has speeded up the aerotriangulation process by a factor of 5 to 10, thus significantly increasing productivity and cost-effectiveness. IDP will permit the generation of further photogrammetric products at a considerably lower cost. Needless to say, the degree of cost reduction attainable compared with today will be dependent on the products concerned. An increase in productivity by a factor of 2, however, can be expected in most cases.

3.4 Block-based Approach

Until now, all photogrammetric systems have operated on a model-oriented principle. Point measurements - whether in orientation or aerotriangulation measurement or in DTM generation - are always performed in only 2 images at a time. Additional epipolar images are frequently required. One decisive advantage of digital photogrammetry, i.e. its ability to perform measurements in several images simultaneously, has not yet been utilized. PHODIS AT is one of the few systems which are no longer based on the model principle, but use the image block as the basis of their measuring strategy. All measurements - automatic tie point measurement or semi-automatic control point measurement - are simultaneously performed in all overlapping images. This block strategy is now being extended to all PHODIS products and will open up entirely new possibilities:

- PHODIS OP can now be extended in such a way that, during orthophoto generation, blind areas are automatically filled with sections from other images. During the generation of mosaics, the block is offered to the operator for the selection of images or orthophotos.
- PHODIS TS can be extended to permit DTM measurement to be performed throughout the entire block, in a similar way to measurement in PHODIS AT. This will markedly increase the homogeneity and accuracy of the DTM. In addition, it will now be possible to measure image sections which are concealed along the strips but are visible in the transverse direction
- PHODIS ST can perform "block roaming" in the stereo mode, i.e. the boundaries of a stereomodel no longer present an insurmountable obstacle. The stereoplotter automatically selects suitable images from the block for display on the stereo monitor. This permits the operator to move within the block without having to give any thought to image or model change, which used to be a classical feature in analytical and analog photogrammetry.
- Like PHODIS ST, PHODIS M offers the possibility of moving across the image or orthophoto block without any need for the operator to remember to load the relevant images.

3.5 Various Sensor Models (Sensor Modeling)

Aerial photos will remain the primary image source for photogrammetry in the future, with satellite-based sensors still being of secondary importance in this field. However, when considering the sharp increase in the demand for small-scale orthophotos and the growing number of suppliers of satellite images, satellite-based sensors must be expected to gain increasing importance in the future. It will therefore be essential for future photogrammetric plotting systems to include capabilities for satellite image processing. Even at this early stage, however, PHODIS is able to handle SPOT and MOMS images, and it will be upgraded for further major sensor models in the future.

3.6 Simple and Intuitive User Guidance

Photogrammetry must increasingly be seen as part of a more comprehensive system. It must be suitable for integration into CAD/CAM and GIS systems. As a result, however, more critical demands will be made on the system with regard to simple and intuitive user guidance. Future operators of photogrammetric systems will increasingly come from non-photogrammetric work areas. Zeiss therefore aims to systematically enhance simple and intuitive user guidance in IDP.

4. CONCLUSION

Generally speaking, digital photogrammetry has opened up photogrammetry the possibilities of automation and to the use by operators without photogrammetric skills. A major element in the enlarged performance spectrum is the transition from the handling of single images or image pairs to a block-based approach and, as a result, to the all-round processing of the project instead of the cumbersome network connection of stereomodels. The implementation of this concept has been initiated in PHODIS and will be systematically continued. This also creates the conditions for the future advance of automated object recognition.
Photogrammetry in the future will greatly differ from what we know today. It will increasingly be used in other systems such as GIS. This will lead, firstly, to new demands being made on photogrammetry and, secondly, to a wider scope of cooperation with related disciplines (GIS, computer graphics, pattern recognition). "Sensor fusion" and "feature extraction" will become natural components of photogrammetry and will open up new markets to it.

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