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Current status of on-line point positioning in commercial photogrammetric systems

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ABSTRACT

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Modern photogrammetric restitution and mensuration systems are inherently fully computer-controlled. One essential advantages is automatic slewing to positions on the photostages defined by computed image coordinates. Common to all conventional and video-assisted analytical instruments, this feature has been incorporated in the software of virtually all available systems. The paper attempts to review the present state of on-line point positioning of a few typical commercial systems. Although utilized also in DTM data collection, interactive graphics data editing and other tasks, computer-controlled positioning plays a major role in on-line phototriangulation, e.g. driving the stages during model orientation, to the location of common tie-and-pass points in aerial traingulation, to known control and check points, also during calibration to predefined grid points.

INTRODUCTION

Present second generation analytical photogrammetric systems make ample provision for computer-controlled positioning and may, from this point of view, be considered as rather mature data capturing devices both in hardware and software. In fact, although not as spectacular as other components – because mostly hidden within other more complex procedures – point positioning as an elementary feature has become an indispensable tool in all existing commercial systems. With the utilization of solid-state cameras built into analytical systems, new possibilities for point positioning have been opened (Helava, 1987).

The following paper is an attempt to give an account of the current status of the use of on-line point positioning in a few commercial systems mainly in conjunction with phototriangulation. Its intention is not so much as to provide a comprehensive coverage of the topic but rather to systematically describe the most relevant features found in commercially available systems. Such an overview, however, cannot be completely free of at least some degree of subjec-

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tivity, particularly because only a limited amount of information was made available to the author.

2 CONCEPT OF POINT POSITIONING

On-line point positioning may be defined as the capability of analytical photogrammetric systems to move the photo stages to any suitable position strictly under computer control in order to facilitate either the human or the machine for further actions. Actually, this is one of the most essential advantages of analytical stereoplotters as compared to analog plotters, and it cannot be overemphasized enough.

Normally, the subject of on-line point positioning is not covered *per se* in the literature. Rather, by realizing its fundamental importance, it always has been subsumed under more general aspects. While (Dorrer (1986) values computer-controlled positioning more from a general operational and independent point of view, Cogan (1986), Helava (1987) and Saile (1987) consider it within the framework of descriptions of new hardware systems or software design concepts.

As the photo stages have to be constantly positioned within the real-time routine anyhow, the necessary hardware requirements for on-line positioning are present in all analytical systems. Therefore, principal differences between various commercial systems can only by due to different philosophies of design and/or degrees of implementation of operational software procedures. Although it is not essential that the photo stages be controlled by dedicated microprocessors such as the P2-Plate Processor of the Kern DSR series or the P-Processor of the Zeiss Planicomp P-series analytical stereoplotters, it is nevertheless desirable in order to relieve the main processor of unnecessary tasks and to distribute processing time. An additional advantage is that, due to standard computer interfaces, stage motion control is independent of the main computer and can thus be considered as more flexible and user-friendly. Actuation of the stage motions is performed by processor-controlled servos with maximum slewing speeds of 30–40 mm s^{-1} at resolutions of 1 μm and accuracy of 2–3 μm.

It is interesting to see the trend towards larger sizes of the photostages, e.g. Planicomp P1 (330mm by 240mm) and DSR-18 (480 mm by 240 mm). This entails that not only Large Format Camera pictures can be measured, but also that two or three adjacent normal-size aerial stereomodels may be processed simultaneously. Point-positioning procedures for image composites, however,require additional programming attention and can thus be found in special software packages only, e.g. CRISP for close range applications (Fuchs et al., 1985).

On-line point positioning is predominantly used during the mensuration phase of phototriangulation, viz. for the selection, identification and transfer of tie points between adjacent overlapping photographs. Subsumed are orientation points if stereomodels are to be formed by relative orientation, e.g. with the Planicomp C100 or P-series. Control points can only be positioned approximately if their corresponding image coordinates have not been measured or exterior orientation parameters are not known with sufficient accuracy. A rather comprehensive treatise of point transfer procedures may be read in Dorrer (1986).

While the along-strip tying of photographs or models is commonplace in the operating procedures of all commercial systems, the on-line methods developed and propagated for cross-tying are considered uneconomic by the instrument manufacturers. Although demonstrated to be effective, precise and highly reliable (see e.g. Kratky, 1982), cross-ties by means of lateral strips seem to be not favored by the majority of potential users due to having to process the photographs of a block a second time. That such a prejudice would easily be outweighed by the fact that preparation time could be considerably decreased, obviously does not matter. Fortunately, with the possibility of digitizing image patches from photographs by solid-state area sensors (Helava, 1987), point transfer across strips can be handled as easily as along strips. The DCCS Digital Comparator Correlator System from Helava (1987) has opened a completely new era of analytical/digital systems.

The time and personnel needed during the preparation phase of phototriangulation is generally underappreciated. A considerable reduction can only be achieved if it is somewhat connected to measurement, e.g. using digital transfer. Since the new generation analytical plotters advocate free-hand cursor control on a graphics tablet, ergonomic solutions for quick selection and identification of triangulation points on photographic prints can be envisaged. Zeiss seems to favor a similar method originating from Ellenbeck (1983). In either case, the captured data will be used for approximate positioning during the mensuration phase.

Point positioning can be classified according to the source from which it originates, e.g. by manual triggering or program control, or the aim for which it is purposedly thought of, e.g. for coarse or fine positioning, for further human or machine intervention, etc. Since the classical domaine of human interaction, viz. selection, identification and mensuration of suitable points, has re-

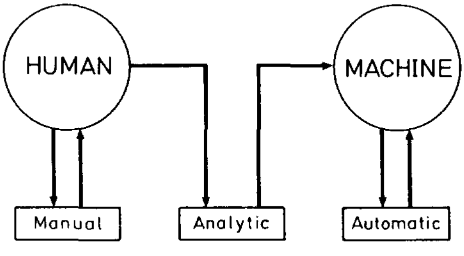

Fig. 1. The three modes of point positioning.

cently been opened for automatic machine handling through digital image processing techniques, a somewhat combined classification into *manual, analytical,* and *automatic* positioning modes seems appropriate (see Fig. 1).

3 POINT POSITIONING MODES

3.1 Manual mode

This type of positioning is characterized by direct human interaction. Individual points, addressed by entering either their image or model coordinates or their identification numbers on the keyboard, will be positioned after initiating a special "MOVE TO" or "VISIT POINT" command or pressing a corresponding button. Clearly, identification numbers can only be utilized if they have previously been attributed to certain coordinate pairs or triples stored in main memory or on file. In both cases positioning can be performed within the accuracy given by the values of the coordinates and by the hardware components controlling the stage motions. As an example, manual positioning for remeasurements may be required in case the normal operational flow of data collection was interrupted for review purposes (Helava, 1987), e.g. after displaying RMS values or differences.

Modern analytical systems are designed as workstations with freehand control rather than hand- and foot-wheels. While the freehand control of the DSR series is connected directly to three encoders, and with a separate 16-button input control board, the consoles of both the Planicomp P1 and the DCCS each have a precision data tablet. The mono-stage DCCS 12-button cursor is an ordinary graphics tablet cursor. The 11-button Planicomp P "Universal P-Cursor" is more sophisticated due to the necessity of having to provide controls to two stages including height.

The data tablet cursor can be used to impart movements under manual control to the image or the stereomodel. Slow (high resolution) and fast (low resolution) incremental movement modes can be selected by pushing appropriate buttons on the DSR series cursor. The P-Cursor has a built-in progressive characteristic that makes its resolution indirectly proportional to cursor speed.

The absolute mode executes fast slew motions under computer control. Normally, a print of one of the stage photographs being measured, or a map sheet covering the stereomodel, is mounted on the data tablet. A special tablet orientation routine provides the link between the print and its corresponding photograph. With the help of a "MOVE TO" button on the cursor, any point of interest indicated on the print will then be absolutely positioned on the photostage.

3.2 Analytic mode

This mode constitutes the core of on-line point positioning. Under control of a particular service routine the computer automatically moves the photo-stages to a precomputed or previously stored position, expecting the human operator to initiate a certain action. Normally, the operator will now perform a measurement either at exactly this position – but on the other photograph – or in its vicinity. This means that controls have to be partially locked by the program or not. As discussed in detail in Dorrer (1986) various measurement modes, such as comparator, model ot joining (digital transfer; see Cogan, 1986) modes, happen to occur during the process of phototriangulation, all of which are incorporated in present commercial systems; e.g. One-sided (asymmetric) and two-sided (symmetric) stereoscopic parellax removal measurements for "old tie points" and "new tie points", respectively; monoscopic or stereoscopic coordinate measurement of control points and auxiliary points. During the waiting or idling stage the system preferrably issues a typical auditory tone (e.g. in the Planicomp C100) thus signalling the operator to take action.

In the analytical mode mainly predefined point sequence or point patters are addressed. The patterns may be fixed or default standard of a particular operational program, e.g. the ordinary 6-point "Gruber"-pattern for relative orientation as favored by Zeiss, or a "Double-Gruber" (Cogan, 1986), or they can be defined by generating a "skeleton" inputfile (Helava, 1987) or "scheme" file (Cogan, 1986) prior to mensuration.

For interior orientation the point pattern may also be precomputed by program depending on the configuration of the fiducials given by the camera type. Similarly in triangulation measurement, default tie point positions and numbering convention may be used. Driving the stages during interior and relative orientation service routines is commonplace in all commercial analytical systems. Double or multiple measurements can be specified and handled alike. There are also programs being offered by the manufactures for calibration purposes. In this case the pattern consist of regularly distributed and consecutively visited grid points.

Although incorporated in all systems, operational solutions for absolute orientation and model connection, however, may rather significantly differ from one system to the other, depending on the measurement modes being implemented in the operating procedures, the degree of freedom (Dorrer, 1986) yielded to the human operator, the way different point types are treated, or accumulated information being utilized permitting suitable conversions between coordinate systems and thus more precise point positioning. While both the DSR series and the Planicomp P1 feature similar concepts in absolute orientation, the strip triangulation procedure proposed for the Kern system is more advanced. This concerns mainly the identification and measurement of ground control points, which can be significantly facilitated by performing a model-to-ground transformation as soon as sufficient control has been observed (Cogan, 1986).

3.3 Automatic mode

The characteristic of this mode is that the photostage movements are used for automatic selection of image scene locations assuring high correlation accuracy. Prerequisite are solid-state array sensor cameras connected to the optical train of each photostage allowing digitization of image patches. These patches can then either be stored digitally and used as inputs to digital correlation, i.e. image registration, or be used in pairs for real-time correlation of the stereogram. Hence, in automatic mode, not only point positioning but also the measurements are, in principle, performed by the machine.

While the DSR series and P1 analytical stereoplotter workstations optionally provide for the connection of CCD-cameras, the DCCS analytical comparator fundamentally is equipped with a calibrated solid-state area sensor. Image correlation experience with the Planicomp C100 (as predecessor of the P1) has been limited to close range applications (program package INDUSURF; see Schewe, 1988). Here, high-precision real-time point positioning along profiles on well defined surfaces is performed in stereopairs. The DSR series Image Correlator is mainly meant for automatic elevation measurements and the derivation of digital terrain models. Point positioning within user-defined working areas and sampling density may be carried out in profile mode or regular grid mode. In high-resolution mode the image patches covered by each camera have a size of 6 mm by 8 mm (Bethel, 1986). A semi-automatic model orientation package has been introduced to allow correlator-aided interior, relative and absolute orientation with the DSR, based on the operator providing some initial positioning.

The DCCS analytical comparator is intended for phototriangulation measurements and shall therefore be considered in some more detail. Because the patches can be stored digitally for later use the DCCS becomes, in effect, a multi-stage comparator, and it is, in a wider sense, the first representative of a new generation of photogrammetric instruments. At the nominal pixel size of 20 μm by 20 μm, the 512 by 512 sensor array covers a window of 10 mm by 10 mm.

By means of a hierarchical "pull-in" approach to correlation in object space (Helava, 1987) two homologous image patches become orthorectified. Candidates for "good" tie points are determined with the Förstner interest operator in conjunction with point positioning. High registration precision on tie points is obtained by simultaneous multi-image least-squares correlation yielding standard deviations of image residuals after ray intersection in the order of 0.1 pixel, i.e. 2 μm.

Once started, the DCCS presently does manage to run through a sequence of photographs fully automatically, though not consistently. Therefore, a semiautomatic mode seems still more economic. The preferred operational flow has been designed such that measurements propagate always from "upper left" to "lower right" with fiducials first, then "old" tie points, "new" tie points, control points and auxiliary points last. The system computer drives the comparator stages to these locations called for by the flow – besides a multitude of other tasks. The DCCS is the first instrument with capabilities of automatic cross-tying between strips without having to reenter the photographs.

4 CONCLUDING REMARKS

Today, on-line point positioning features are essential integral components of both conventional and video-assisted analytical systems. Their utilization has matured to a large extent and spectacular developments are not to be expected any more. In the automatic mode, we still have some way to go before every triangulation system is equipped with the software and hardware to allow reliable, accurate automatic point positioning/determination. From an academic point of view, it is perhaps not a spectacular improvement, but such systems are by no means functioning and standard in practice. When they are, that will be rather a large step forward in production triangulation.

Naturally, point positioning is being employed also in other than triangulation work, such as in DTM data collection or in revisiting of already observed point sequence for monitoring purposes, and under different hardware support, e.g. VIDEOMAP for optical overlays of graphics data on the photo for online checks. The subject of the review paper, however, has been deliberately restricted to phototriangulation applications. Instrumentation for on-line phototriangulation tends to be directed towards analytical/digital comparators such as the DCCS. For fully digital systems to be envisaged in a not too distant future, point positioning, though still relevant, will be completely relieved from the mechanical limitations inherent to analytical systems.

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