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NEW CHALLENGES OF CLOSE RANGE PHOTOGRAMMETRY

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1. HISTORICAL BACKGROUND

The technical development goes in phases. Each phase starts with an invention or a technological break-through, which forms the basis for new instruments and methods. After some time this technology will be fully developed and refined and then it is not possible to develop it any further. At this stage we can expect a new technology to take over the development and replace the older one.

This pattern of development is also applicable to photogrammetry. With the invention of photography photogrammetry started as the science and art for map compilation. In the latter part of the 1800 planetable photogrammetry provided vertical and horisontal angles for intersection calculations. This phase of photogrammetric development was ripe and mature at the turn of the century Pulfrich (1901 and 1902) and Fourcade (1901, 1902) independently invented the stereocomparator for the identification of homologous points in a pair of photos.

The second big phase of photogrammetric development began with the invention of the stereoautograph. Two independent inventions by von Orel-Pulfrich (See Manek 1958) and Vivian Thomson (1908) started the era of analogue photogrammetry. A strongly contributing factor to the development was the invention of the airplane by the brothers Wright in USA shortly before the first world war. During the analogue phase photogrammetry became the established tool for map production.

The third phase of photogrammetry is the analytical one. It is based on the invention of the electronic computer. Photogrammetrists very early started to use the computer. Modern mono- and stereocomparators appeared around 1960 and the analytical aerial triangulation began to develop. Simultaneously the non-topographic applications of photogrammetry got a revival because of the flexibility of analytical photogrammetry compared to analogue. During the 1970's a series of analytical plotters became available from various manufacturers. The photogrammetric community now got a workhouse for production of maps both in graphical and digital form. The analytical plotter not only made the map production and measurements of DEM's and aerial triangulation more effective, but also opened new possibilities for the application of non-topographic photogrammetry at close ranges. The analytical era of photogrammetry seems to have reached its summit in the 1980's.

The fourth big phase of development of photogrammetry is the digital photogrammetry which is based on images that are stored digitally in a computer. The photogrammetric community was first faced to this type of images 1972 when the first LANDSAT pictures were presented to the ISP Congress in Ottawa. Imaging remote sensing has ever since continued to provide new instruments and methods for the evaluation, interpretation and measuring of digital images. For close range photogrammetry the main interest is devoted to the use of CCD array sensors for either direct recording or digitalization of parts of photographs. This later development is still in its infancy, but many research groups investigate and develop methods for photogrammetric applications of CCD images.

2. ANALYTICAL PHOTOGRAMMETRY

Analytical photogrammetry has had a fantastic development. It has been an interaction between methods and software on the one hand, and tasks, problems and needs from the practice on the other. This has lead to a rich variety of applications in close range photogrammetry. As photogrammetrists we can see two groups of methods, one which uses ordinary cameras and digitizers that you can by of the shelf in the computer store, another which uses high precision photogrammetric cameras and analytical plotters and comparators. Common for both approaches of image acquisition and measurements is that you always will need appropriate software for the reduction of the measured image co-ordinates.

The analytical approach, as opposed to the analogue, makes it possible to use arbitrary photostations and directions, and the object may have any shape and the result can be presented in any form in any reference co-ordinate system. But the inherent flexibility of analytical close range photogrammetry is directly limited by the computer programmes for the evaluation of the photos. The programmes have to be able to work under very general assumptions, so as to allow for all the flexibility of photogrammetric problem solving and network design. If you e g have a software that presupposes the common geometry of aerial photogrammetry, then you will be rather limited when you have a close range photogrammetric problem to solve. Not all cameras have 4 fiducial marks symmetrical to the principal point, not all stereomodels are close to the normal case, not always is the overlap 60%, not always is the subject under study comparatively flat and parallel to the image planes. In close-range photogrammetry you seldom have possibility to make relative orientation with the six cardinal von Gruber points, which may lead to large model deformations. And the classical division of absolute orientation into scale determination, levelling and planimetry adjustment may not always provide the best reference to the given co-ordinate system. Thus in summary for the general cases of photogrammetric geometry in design you will need a very general computer programme to be able to make use of all the possibilities offered by analytical photogrammetry at close ranges.

Now, what do we mean with a general photogrammetric programme? The functional part of the mathematical modes is based on the collinearity equations between object point, perspective centre and image point. The image co-ordinates x'y' are measured, the object point co-ordinates XYZ are the unknowns, and the position of the perspective centre and the orientation in space of the image are parameters. A general programme also has parameters for radial and tangential (decentering) distortion. Instead of these parameters, or in addition to them, so called additional parameters can be used to model systematic deviations from the elementary collinearity geometry of the imaging. For the solution of the equation systems we first have to linearize the equations by a Taylor's series expansion. In order to do so we need approximate values of all unknowns and the programme has to be able to compute such approximate values for arbitrary values of the orientation parameters.

In order to present the photogrammetric result in a given co-ordinate system we need information for the absolute orientation. In the mot simple case XYZ co-ordinates are given for a set of points. But it must also be possible to introduce other kinds of information for the absolute orientation, such as angles and distances, points on straight lines, points or planes etc. These lines and planes may have vertical or horisontal or any other given orientation, or not. If we go one step further we want to have a programme that can handle any combination of photogrammetric, geodetic and other type observation in one and the same adjustment. Such programmes are ORIENT (Kager 1980), CRISP (Fuchs and Lebert 1982), MOR (Wester-Ebbinghaus 1983), STARS (Brown 1982), BINGO (Kruck 1984) and GENTRI (Larsson 1982).

When we talk about information for absolute orientation we also can mention the possibility to use generalized inverses. If for instance we do not have information for a complete absolute orientation, it may be possible to solve the measuring problem without it. Examples of this may be found in deformation analysis and in shape control of structures. In these cases the use of generalized inverses is very advantageous. They are also useful to solve the problem of over-parametrization. Generalized inverses have been used in close range engineering photogrammetry by among other Frazer (1982), Duane Brown (1982), Granshaw (1980, 1982) and Cooper (1985).

3. MODELS FOR STOCHASTIC ERRORS

In the most simple case adjustment of observations is based on the assumption that the observation errors are independent and normally distributed with the same variance. You can only justify such a simple stochastic model when you have only photogrammetric observation and given co-ordinates for absolute orientation that is at least one magnitude more accurate that the photogrammetric co-ordinates, or when there are no redundant observations for the absolute orientation. As a rule we have to assume a certain standard error also in the given control points. Then we can introduce also the control points as unknowns in the adjustment and at the same time include the given co-ordinates in the adjustment with their appropriate weights. In a similar way we have to introduce weights for other types of control information, such as straight lines, planes, angles and distances. The same also applies when we introduce in the adjustment direct observations on exterior orientation elements of the images, and on constraints between unknowns in general.

If we have the inner orientation elements as unknowns in the adjustment, we can introduce old values thereof into the adjustment with their weights, or even better with its weight matrix. This weight matrix should be taken as the inverse of the variance-covariance matrix from the previous calibration. This is even more important in cases when the calibration calculation leads to large correlations between the inner orientation elements (Wrobel 1978). If the calibration is old and we doubt its reliability we have to decrease the weight accordingly.

We also have to scrutinize the assumption that all image co-ordinates have the same weight and are independent. First we have assume a well developed functional model based on the collinearity equations complemented with parameters for radial and tangential (decentering) distortion and regular emulsion shrinkage (Helmert or affin).Then we can recognize some major physical causes of stochastic errors, such as irregular film (or emulsion) shrinkage, unflatness of the emulsion, irregular deviations from the lens distortion, atmospheric refraction, instrument and operator. Except for the operator (and perhaps parts of the instrument contribution) all these causes give errors that change more or less continuously over the image. Sudden changes in direction and size of errors are not to be expected. The consequence is that image errors show a strong autocorrelation for short distances between the points in which the errors occur. For increasing distances the correlation will decrease. (Schroth 1982). The above mentioned physical causes of errors can also be expressed as influences on the image co-ordinates and form a basis for a variance component model that can be derived by an application of the general law of error propagation (Torlegård 1987). With such a model one can estimate the magnitude of the individual errors. In developing a variance component model one soon finds that there exists a considerable correlation between the x'- and y'-co-ordinate of a point. This has also been shown by Brown (1969). (See also Mannual of Photogrammetry Paragraph 4.8.8).

It is often the case in engineering applications of close-range photogrammetry that the accuracy plays a decisive rôle for the design of the photogeometry. The estimation and prediction of errors then becomes most important. Correct estimation and prediction must be based on functional and stochastical models of the kind that are indicated in the above.

The stochastic model also comprises the theory of reliability i.e. the effect, detection and elimination of blunders, mistakes and gross errors in observations. The method of data snooping by Baarda (1968) and the use of robust adjustment methods (Werner 1984) have already been used in engineering close-range photogrammetry. The planning and design of the photogrammetric project comprises not only choice of cameras, stations, orientation angles, and a prediction of accuracy of the object co-ordinates, but also an investigation of the reliability of the planner photoblock (Torlegård 1981) and (Frazer 1984a and 1984b). This method of planning applies to point determination, but for cases when graphical output in the form of contours or profiles or other line drawings, then it is a little more difficult to garantee reliability. One possibility is to repeat the drawings from another stereopair. Then somebody will react and says that such a method will be too expensive. But reliability in technical terms will always cost a lot.

Thus, in summary, the planning of a photogrammetric project will contain

- photo stations and photo orientation and the necessary control information to define the datum (reference system)
- optimization of the precision of the unknowns to be determined
- optimization of the reliability, i.e. control of blunders and their effects.

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4. DIGITAL PHOTOGRAMMETRY

We understand with digital photogrammetry that the image is stored in a computer as greyvalues. These greyvalues are given in a picture element matrix, pixel matrix, in which the indices of rows and columns define the position in the image, they are the image co-ordinates. The greyvalues are often given in 8 bits. The pictures can be shown on graphical terminals. With a cursor one can read out the image co-ordinates in the unit of one pixel-spacing. Stereoscopic pictures can be viewed on a split screen, or on twin screens with the aid of a mirror stereoscope (Torlegård 1986) or with the anaglyph method on one screen with one picture in red and the other in blue-green colour. (Alberty, König 1984).

The data acquisition for digital close-range photogrammetry can be done with various instruments. As photogrammetrists we first think of the possibility to digitize existing photogrammetric pictures. This can be done on-line or off-line from the rest of the photogrammetric process. Such a photo digitizer has recently been released from Rollei (Ester-Ebbinghaus 1986) which uses a reseau for precise definition of the image co-ordinate system. At the department of photogrammetry of the Royal Institute of Technology we started to use digital techniques some five-six years ago (Torlegård 1986) and then we digitized pictures in a machine developed at the department of physics (Åslund et al. 1977). Last year we bought an analytical plotter, the Kern DSR-11, that was equipped with CCD-cameras for digitalization of small patches of the stereoscopic pictures in the stages. The firm Zeiss from Oberkochen also offers a similar instrumentation, the Planicomp with digital correlators. Such systems are ideal for the photogrammetrist, because he can easily relate and compare the results of digital methods with the corresponding from analytical methods of classical photogrammetry.

A second way of acquisition of digital image data in close-range photogrammetry is to use video cameras and so called frame grabbers that store the image pixels in an image memory. The videocameras can be substituted by CID- och CCD-cameras for better geometric stability of the images. A stereo video system for real-time photogrammetry has been developed by the firm Hasselblad Engineering, Sweden. It has among other thing been applied in underwater inspection of oil platforms in the North Sea. CCD-cameras has been used by Wong 1986, El-Hakim 1986 and Haggrén 1986 to compose digital photogrammetric system for real-time measurements of points in 3D space. One major limitation with these camera system is the resolution. The number of pixels is typically 512x512, with a pixel spacing of 25µm. When a photogrammetrist compares this resolution over the image field with that of a traditional photograph the resolution of the latter is many many times better. Or if he wants to have the same angular resolution of his digital camera as with his photogrammetric one he comes to cameras with a very narrow opening angle. Attempts to overcome this limitation for close-range photogrammetry have been demonstrated by Rollei and Kern. Rollei has an ordinary reseau camera which has been equipped with a backing that contains a movable CCD-array. The size of the array is a little bit larger than the distance between the resean crosses of the camera. The imaging of these crosses makes it possible to define the image co-ordinate system precisely also in the digital recording. A quite different approach has been made by Kern. They have taken a digital theodolite and placed a CCD-array in the virtual image plane of the reticule. The CCD now acts as "eye" for the computor that analyses this image. Kern has built a system based on two such theodolites. They are programmed from a processor which is a slight conversion of the plate processor of their analytical plotter. A large number of the rutines of the main DSR program can also be used in a host computer of the system. The system is firstly designed for resection from and intersection of targeted points. It would, however, be possible to develop programmes for real time image correlation for the determination of non-targeted features in the object space.

The precision of point determination and parallax measurement in digital images has been a topic of great interest for some years. The most simple and direct way of measuring digital image co-ordinates is of course to identify the pixel position by its row and column numbers of the array. Doing so the precision will be limited by the rounding-off error, which yields a standard deviation of $1/\sqrt{12}$ of the pixel spacing. (Torlegård 1985, Wester-Ebbinghaus 1984). With a pixel size of 25 µm the ultimate precision would be ∿8 µm with this type of measurement. This may suffice for some applications but photogrammetry in general reads image co-cordinates with a precision of 2-4 µm. In order to reach that, more advanced methods has to be applied . Methods for finding the centroid of the image of a target has been developed for photogrammetric purposes, see e.g. Mikhail et al. 1984 and Luhmann 1986. Förstner 1986 has studied the location of image edges as a function of pixel size, pixel spacing,grey-level slope and height of the edge, length of the edge, quantization, analogue to digital conversion, and signal to noise ratio of the image. He arrives to the conclusion that targeted points in photogrammetric images of good quality can be measured with a precision of 5-10% of the pixel spacing. Trinder 1986 reports a precision of 1/5 of the pixel spacing.

Another field of great interest is the measurement of parallaxes between images, i.e. image matching or image correlation. This has applications in relative orientation, in point transfer in aerial triangulation and in measurements for digital elevation models. In close range applications this can be directly transferred to adjustment of image blocks and to measurements of object shape. For photogrammetry two methods seems to be paid more interest namely, maximization of the correlation coefficient and least squares matching of grey-levels. For the matching of two stereoscopic pictures, we always have to consider that they are two different perspectives of the 3D object. This fact is of particular importance for the optimal size of the matching windows. It is very seldom the case that the local geometry of the pictures are equal. Due to slope of object surface relative to image planes we at least must introduce an affine transformation between position of homologous points in the two images as an approximation of the perspective differences. Now it often happens that the grey-level variations (the signal) within the window is too low to calculate a reliable match. Then one has to make the window larger, but doing so the shape of the object will show more height variation that the sloping plane. That means that we will have to model also the object shape when we match the two images. This leads to a multipoint matching method. Here it is also possible to introduce constraints between the points in order to bridge over image areas with low signal content. Such methods has been developed and studied by Rosenholm 1987. One significant result of his studies is that the number of successful matching increase considerably when least squares multipoint matching is used instead of single point least squares matching or maximization of the correlation coefficient.

Digital point transfer has been compared to human transfer in aerial tringulation by Pertl 1986. He found a standard error of unit weight in the adjustment of 4 µm with automatic correlation as compared to 2.4-2.7 with human transfer. The same relation also hold for root mean square values of discrepancies in check points.

Another empirical test has been reported by MengXiang Li 1986. The Kern DSR-11 with automatic correlation was tested for accuracy using the six test areas for the ISPRS comparative test of DEM. For these stereomodels he found the automatic correlation both slower and less accurate that the human operator. In this case the automatic parallax measurement is based on maximization of the correlation coefficient. To speed up the calculations a special parallax processor would be needed. The reliability would be improved by constraints between adjacent points or by variation of the matching window and multi-point matching.

In order to understand and interpret the results of accuracy tests on automatic digital correlation it also becomes interesting to calibrate the CCD cameras for geometry and radiometry. See e.g. Gülch 1986 and Almroth 1987. They both found systematic errors in the sensitivity of the pixels of such a nature that it would influence the correlation results, at least for large correlation windows.

5. PROSPECTS FOR THE FUTURE

With the present interest in digital photogrammetry it is most likely that we soon will have something like the automatic stereooperator, which then would be based on digitization of patches of stereopictures in an analytical stereoplotter. Such an instrument would itself measure the fiducial marks, and reconstruct the relative orientation. It would, however, need some help in the absolut orientation for finding the first 2 planimetric control points. Then the instrument itself would measure the parallaxes and create a DEM of the scene and print orthophotos and any perspectives over the area.

We will also see a development of digital photogrammetry where the basis instrumentation is of the kind that is used in digital analysis of remote sensing data.

More and more companies like MacDonald, Dittweiler, ContextVision, Dipix, Teragon pay an increase interest in the development of digital photogrammetry. Here the full scene will be digitized and stored in the computer before evaluation. In such instrument systems the photogrammetrist also would be offered all sorts of image processing tools from basic filtering techniques to advanced image understanding and interpretation based on artificial intelligence.

A further development of analytical photogrammetry at close ranges is also to be expected in the engineering applications. The CAD/CAM/CAE computer aided design, manufacturing and engineering can make more use of the analytical plotter for such tasks as input of terrain shape of construction area, shape of clay models of cars in early design stages, recording of as-built structures for revision of digital databases, checking production units for shape and size, monitoring of deformation. In these applications of photogrammetry, the analytical stereoplotter will be regarded as a more sophisticated work station connected to the CAE-system.

The technical development also challenges the education system. In Europe most photogrammetrists have a basic education as land surveyors or civil engineers with emphasis on construction and high way design. Their education has to be such that they are prepared to use the new tools that will be made available. They should not be a special kind of electrical engineers or computer scientists but still remain land surveyors and civil engineers able to solve their particular application problems.

The research and post-graduate education in photogrammetry has to cross borders to other disciplines in order to develop new methods, instruments and systems, so that we photogrammetrists can continue to serve as mensuration specialists for various applications.

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