Photogrammetrische Woche 1991
Schriftenreihe, Heft 15, 1991
Institut für Photogrammetrie

STRUCTURAL CHANGES IN PHOTOGRAMMETRY

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1. Thorough Changes

1.1 Everybody feels that we live in a world of thorough and uncomfortably fast changes. They concern the general conditions of human existence, our every day lives, as well as the standards and demands of professions. Particularly striking changes are apparent in today's world of science and technology. Also in our disciplines of geodesy, surveying, cartography, photogrammetry and related fields we have experienced revolutionary developments, which we have partly pushed hard ourselves.

We are inclined to think that developments, especially in technical fields, evolve steadily, responding to continuously increasing demands. However, that model of development is certainly too simple to be adequate. Many changes are violent and constitute breaks. Looking back over the last 20 or 30 years we realize how thoroughly our profession has been affected. Practically all tools and methods which we apply today are totally different from what for instance I learned during my professional education in the 1950s.

1.2 Recently, the developments in technology and their effects on technical professions even seem to accelerate. Changes and discontinuities happen faster, the effects spread wider, and the inherent possibilities get more fantastic in big jumps. The mapping world is striving to stay abreast with the developments. Established organisations struggle hard to balance traditional structures with new demands. Even established industries are changing, and new companies grasp for new opportunities.

We ask ourselves whether the violent development can persist. Will the technical performance in our profession continue to explode? Are we up to major changes, or major shake-ups, in the decade to come? Personally I am inclined to believe so. I expect that photogrammetry and related professions continue to be pushed ahead strongly, to new performance and to new structures.

I shall try, hereafter, to analyse the ongoing structural changes and draw some conclusions.

1.3 Of course,we would like to understand the process, and may ask the general question: What is driving the development, the tools or the needs? Whilst this is a philosophical question, related to the evolutionary mental equipment of man, a superficial answer may suffice here. In my opinion it is often the available tools which actually drive the developments. What seems possible tends to be realized. The needs, which seem to motivate, to launch, and therefore to push developments are more often anticipated potential needs rather than immediate needs. In reality technological, socio- economic, and cultural developments are obviously most complex processes with intricate feed back relations between the development of tools, their real or imagined necessity, and their expected applications. They would certainly deserve more thorough investigation.

With regard to photogrammetry it is undisputed that the recent development has generally been launched and framed by the development in electronics, computer technology, and computer science.

2. Milestones of Technical Development in Photogrammetry

2.1 Improvement of performance

Looking back over the past 30 years in photogrammetry we can distinguish great developments in several directions and on several levels. Let us first consider and identify as obviously primary motivation of technical development the desire or need for improved performance, leaving aside the intricate question how much desired and envisaged improvements are interrelated with the possibilities given by new technical means. The general technical development, in particular electronics and computer technology, continuously open up new possibilities for improving the performance of instruments, of methods, or of systems, leading to improved results.

In many cases the initial desire or motivation of improving performance, by making use of new tools, methods, conditions etc., can be clearly identified. Thus, we recognize as a primary source of development the desire to make our work more precise, more efficient, faster, more reliable, less costly, more economic, wider applicable, or whatever the anticipated single or combined effects may be. Sometimes the performance improvement may not be realized directly but only indirectly via added value or total system advantages.

The development in photogrammetry can be reviewed and understood from the point of view of increased performance achieved technically by increased use of computer technology and computer methods. We review here quickly the main and well known milestones from that point of view, the overall trend having been formulated often enough: From analog via analytical to digital photogrammetry.

2.2 Analytical photogrammetry

2.2.1 Analytical aerial triangulation

Around 1960 the transition from analog to analytical photogrammetry started to become the major general development in photogrammetry for about 20 years. It is entirely based on the availability and greatly increased performance of digital computers. It comprises the computation of object points from image coordinates, by making use of the basic perspective relationships (wrongly called collinearity relationships). Its main manifestation has been the development of modern aerial triangulation, especially of the various sophisticated forms of block adjustment. The total progress has been most remarkable. Aerial triangulation has improved its accuracy and economy enormously. It has had great impact on the general system performance of photogrammetry and is now used almost anywhere, quite regularly.

2.2.2. Digital elevation models

The digital elevation models (DEM) represent another milestone of development in photogrammetry which is also the result of consistent application of computer methods. Again, like in aerial triangulation, the human operator still handles the measurement part which has not much been developed beyond conventional standards, except for computer controlled steering along profiles or to grid points. It is really the data processing which has made the DEM an accurate high quality and versatile product.

Photogrammetrische Woche 1991
Schriftenreihe, Heft 15, 1991
Institut für Photogrammetrie

2.2.3 Analytical plotter, analytical orthoprojector

The digital computer has also greatly influenced the design of photogrammetric stereo-instruments. The analytical plotter now governs the scene. The now classical analog stereo plotters have been abandoned in the sense that they are not manufactured any more, although quite a number of them is still in practical use. The analytical plotter is essentially an instrument with a built-in digital computer as its main component which handles the projection relations between object and image points as prime task. It also serves as or is combined with a general purpose computer, which is applied for many data editing functions and additional data processing.

The concept of the analytical plotter is more than 30 years old (Helava 1957). Also the previous attempts to produce mechanical analytical plotters (Zeiss Supragraph) may be recalled. It is noticeable, in this respect, that the analytical plotter became successful and generally applied only during the last decade, after the digital computers had reached a sufficient level of performance and of comfortable data handling.

The result today is conspicuous. Modern analytical plotters represent a much higher level of accuracy, of convenient handling, of speed of operation and especially of versatile application than their analog ancestors. They also have greatly supported the acceptance of digital data and digital products by users in general.

Supplementary to the analytical plotter the analytical orthoprojector is to be mentioned, standing in the same line of development. Computer driven orthoprojectors have certainly established the acceptance of photo- and orthophoto-maps by rendering the required performance of accuracy, quality, and economy. All previous optical type orthoprojection instruments have not survived.

2.3 Digital maps, digital data bases

2.3.1 Digital mapping

Graphical plotting has been the major output of aerial photogrammetry for a long time. It is decisively based on the ability of the human operator to recognize and extract object features by stero-vision and stereo-measurement, to map them, and to attribute cartographic signatures to them. It seemed impossible - and still is to a great extent - to replace the human operator in this function. Nevertheless, photogrammetric mapping has undergone great development by making use of computer technology and graphical data processing. As a result graphical plotting of map manuscripts has evolved into digital mapping.

The development started simple enough by computer assisted plotting. With a mini-computer of very limited memory capacity, interfaced between the photogrammetric stereo-instrument and the plotting table, simple graphical functions were performed (like plotting straight lines, parallel lines, adjusted rectangles, curves, symbols, hatching etc.) and passed on for on-line execution, with only short delay, to be plotted on a computer driven plotting table. The original idea was only to produce edited plots, saving the draftman. Soon, however, the graphical functions became more complex, the memory demands increased, and the editing grew out into pretentious cartographic modelling, simply because the mini-computers soon offered the possibilities.

At this point in the development the interactive graphical workstations appeared (see below).

Photogrammetrische Woche 1991
Schriftenreihe, Heft 15, 1991
Institut für Photogrammetrie

They can generally handle graphical data and constitute the central command station in a mapping system. They are on the one hand interconnected with external data bases and can, on the other hand, play back information into the photogrammetric stereo-instrument for checking or updating. The connection with graphical workstations has transformed the previous plotting station into a mapping system. Greatly extended software determines the performance and the range and comfort of application.

Such mappings systems are now highly developed tools for digital photogrammetric mapping and the related cartographic modelling and editing. Mapping with digital output is today on a completely different mode of operation and level of performance compared with only 10 years ago, although the human operator is still the essential part of the system. The direct result is not any more the graphical plot but the data file for the digital map, containing all editing instructions and cartographic symbolisations. Thus, a complete shift to digital graphical data has taken place. Graphical plots or displays on screens are only visulisations of the digital data which constitute the essential product of the mapping operation.

2.3.2 Digital topographic data bases

It is a small step only to go from the concept of a digital map to the digital topographic data base. The object capture in the stereo-instrument is practically the same, from the technical point of view, although it may comprise more objects than are traditionally represented in maps. The interactive graphical workstation is again the central part of the system. Consistency monitoring, correcting, and editing of the data becomes even more important as the product goes into a data base of a geographic information system (GIS), and visualisation is not the directly essential goal.
The techniques and methods mentioned here connect closely with very similar developments in cartography. Thus, cross-references are due to automation in cartography, cartographic landscape modelling and cartographic data bases.

2.3.3 Interactive graphical workstations

In the above 2 paragraphs the interactive graphical workstations have been mentioned. They have been developed outside photogrammetry, but we make use of them at different levels of operation and performance. They are essential for producing digital maps or digital data bases. In combination with the photogrammetric stereo-insturment, i.e. the analytical plotter, graphical workstations have essentially 3 functions: (1) They are central stations where the complete execution and editing of digital mapping takes place and where the digital map is produced. (2) They are connected with external data bases and can merge and integrate data of different sources. (3) Intermediate or external graphical data can be projected back into the photogrammetric instrument. The superimposition on the stereo-viewing of the photogrammetric model allows convenient visual checks for completeness of the mapping, for applying corrections, for assessment of changes and for thorough quality control.

2.4 Digital photogrammetry

The most recent development in photogrammetry is concerned with the transition from analytical to digital photogrammetry. Digital methods are essentially still in the research phase. However, first applications are already practicable, and the system development is just emerging, ready to be introduced and utilized in a number of fields. Again, the platform for the

Photogrammetrische Woche 1991
Schriftenreihe, Heft 15, 1991
Institut für Photogrammetrie

development is given in first instance by the progress in technology, as far as image sensors and computer hardware are concerned and, related to it, the evolution of powerful computer-software and -methods, as well as computer science concepts.

2.4.1 Digital image processing, first level

All procedures of digital image processing, in relation with photogrammetry, operate on digital or digitized photography (see below). Applications in conventional aerial photogrammetry in particular are based on digitized photographs, for the time being, as digital air survey cameras are not yet in sight. It implies that the hardware requirements for image data storage alone are quite high. Similarly, access to and processing of image data ask for hardware performance which is much higher than for analytical photogrammetry. Certain solutions can be kept simple, but we should realize that digital photogrammetry in general operates on a high level of computer performance which in turn, becoming available, motivates intense development.

Digital image processing attempts to do the geometrical, physical and semantic object reconstruction (object modelling) from digital images, with the help of computer processing. That aim is far too general to be totally successful, at present. Therefore some basic subdivisions have to be considered.

Image processing is concerned first with elementary (low level) operations like image enhancement, geometric and radiometric image restauration, including filtering, smoothing etc. Another type of local image operations is feature extraction, especially point- or edge extraction. For photogrammetric application particularly interesting operations are point identification (e.g. fiducial marks and control points), measurement of points, and especially image correlation or image matching. Concerning image matching there are basically 2 different procedures, known as least squares matching (operating on grey level values) and feature based matching (operating on gradients). The matching operations as such may be simple procedures. However, they relate to 2 or more images and thus represent a more demanding level of operations which is equivalent to the human stereo-vision capability. Image correlation by least squares matching has shown to be more accurate than human stereoscopic height measurements.

The digital image processing operations mentioned are essentially algorithmic operations which do not require knowledge nor human interference. They are capable, therefore, of being automated to a great extent. On that level of image processing already a number of operations can be executed which are highly significant for photogrammetry. It includes precise point measurement of signalised points in particular, or of fiducial marks. Thus the application in analytical photogrammetry (in industrial photogrammetry especially) is open. As far as stereo- or multiple overlap is concerned, image matching is capable of precisely measuring parallaxes, thus it can perform orientation tasks and measure heights. More striking is the automated DEM capture and automated aerial triangulation. Both applications will be highly important. Automatic surface measurements applied to car body reconstruction, in close range photogrammetry, has been in regular practical application for some time. It shows that image processing has technically evolved beyond preliminary stages of development and is going to give highly interesting practical results, more precise and faster than conventional manual methods are capable of. Thus, the first goal of improved technical performance by digital image processing has started to be realized in some fields of practical application. One particular example will be the production of digital orthophotos.

2.4.2 Digital image processing, second level

The examples mentioned above are generally characterized by not depending very much on the human operator. That is the reason why automation by digital image processing on that level is possible and will soon be ready for practical application, the technical tools becoming available at present.

A much more difficult case of automation by digital image processing are tasks which require knowledge and intelligence. The human operator is extremely well capable of recognizing objects or relations and structures in images, especially in stereo viewing. Image processing on the higher levels attempts to take over such functions. Knowledge based methods and expert systems are the key words from computer science. It is still a long way until we can expect topographic objects to be automatically recognized in digital images. Nevertheless, successful first steps have been solved already. It is possible, for instance, to identify topographic control points automatically, or to find and locate houses, if approximate values are given. Also automatic extraction of linear features, like roads etc., is quite ready for application.

2.4.3 Interactive digital image processing

Digital image processing methods which can replace the human operator from tedious measuring work and perform the tasks faster and more precise represent one line of development which is successfully pursued. There are many essential operations, however, which depend partly or fully on human interaction and cannot easily be automated. Therefore interactive digital image processing on the basis of the newly emerging digital photogrammetric (stereo-) workstations, or briefly digital plotters (see below), represent the second line of development to be pursued. Such systems can combine automated methods with human interference, guidance, classification and decisions, based on the knowledge, experience and intelligence of a human operator. The interactive mode of operations covers especially the whole range of digital mapping and digital topographic data bases as described in section 2.3. Interactive digital image processing, combined or supplemented with automatic digital image processing, will certainly represent the future of stereo-photogrammetry for quite some time.

2.4.4 Remote sensing, multispectral classification

This paper concentrates on the development of milestones in photogrammetry. It should not be overlooked, however, that in remote sensing digital image processing has started and has had a long development which has reached successful application in various ways. All low level operations have been developed and elaborated first in remote sensing. Above that level image transformations, feature extraction, change detection and especially multispectral classification have been developed to a high degree of applicability. The MS classification is particularly interesting and important as it has no equivalent in operator based image analysis, aiming at physical rather than geometrical object identification. Both aspects will have to be integrated one day, merging geometry oriented photogrammetry with remote sensing.

2.5 Sensors and instruments

The above review has been concerned almost completely with the impact of computer performance and computer methods on the execution of photogrammetric tasks and on the improvement and modification of results with regard to the various components of our work as well as to the total system. Indeed, methodical development in the wake of computer technology has really changed photogrammetry thoroughly and continues to push it to still higher performance.

Attention has also to be drawn, however, to the general progress in electronics. It has brought new sensor and instrument developments which also have had and will have a great impact on the execution and performance of photogrammetry. They also represent important milestones of technical development in photogrammetry.

2.5.1 Digital cameras

Aerial survey cameras today have, seemingly, the same design as always, based on optical lenses, mechanical shutters and film. There have been, of course, recent technical improvements, referring to better optics, infracolor photographs, internal electronics, navigation aids, and FMC. Image quality is considerably better than it used to be. But it is true that no attempts have been made, nor will be made for some time, to replace film by semiconductor CCD area arrays in air survey cameras for image capture.

There exist, however, truly digital cameras, known as CCD cameras. At present, CCD cameras have still very limited image formats only, going beyond arrays of 1024 x 1024 pixels only tentatively. Therefore such digital cameras can be applied, for the time being, in close range photogrammetry only. There, however, they have started to be used for truly photogrammetric purposes. It can be expected that their technical performance will improve and that their application in digital photogrammetry will expand.

At the other end of the scale range, photogrammetry and remote sensing from space have gone through a remarkable sensor development. Landsat-TM and SPOT mark the standards for digital imagery from space, apart from digital radar images. Especially the digital multispectral images have been widely used. The digital panchromatic SPOT images have almost closed the gap to digital photogrammetry, although the images have no truly perspective geometry. In the same line the design of the MOMS digital linear array camera with along-track stereo as standard mode is to be mentioned. It will have 4.4 m pixel resolution on the ground.

2.5.2 GPS, Laser profiler and -scanner

There are a number of external sensor and system developments based on technology progress in electronics, which are of great interest to aerial photogrammetry. The first development concerns the satellite based NAVSTAR Global Positioning System (GPS). It will allow precise kinematic positioning of airborne cameras (or sensors). Its application will have a great effect on the economy of aerial triangulation making ground control redundant almost entirely. The second development concerns the direct capture of digital elevation models by airborne laser profiler or scanner. In special application areas (forests) it has already proven its high accuracy performance. Those systems will certainly be part of the photogrammetric scenario in future.

2.5.3 Digitization of photographs, photo scanner

Digital images are the basis of digital photogrammetry. As we have seen, aerial photographs still constitute the majority of images photogrammetry deals with. They have to be digitized in order to make them utilizable for digital processing methods. Specific photo- or image scanners have recently become available which meet the requirements for resolution and geometric accuracy which high precision digital photogrammetry demands.

Photogrammetrische Woche 1991
Schriftenreihe, Heft 15, 1991
Institut für Photogrammetrie

2.5.4 Digital plotter, digital photogrammetric stereo-workstation

The latest instrument development in photogrammetry is the digital workstation, or the digital plotter as it may be called. Such instruments are just emerging, hopefully meeting the high standards of performance, which digital photogrammetry has to set in view of its high claims. Digital plotters are supposed to be the general photogrammetric stereo-instrument or -station working with digital image data. Such instruments are to replace the analytical plotter. Thus, they must have all functions and applications which the analytical plotter has. In addition, they must have as many digital image processing functions as possible for automatic processing. In this way the interactive modes of operation will first be supported by automatic and fast procedures (for measuring tasks in particular). In second instance the interactive modes of operation will gradually be reduced, in favour of more and more functions being taken over by image processing algorithms. Eventually, the human interference in the process should be restricted to the truly knowledge- and intelligence- dependent functions which cannot be efficiently automated for some time. That complex will be the main object of development in photogrammetry in near future.

3. Methodical and Thematic Expansion

3.1 Beyond improvement of technical performance

In the previous chapter the major milestones of recent development in photogrammetry have been reviewed. All development steps can be seen essentially as the result of increased application of computer- or computer related hardware and of computer methods. Thus, technical possibilities have been exploited in order to improve the methods and the results of our work, i.e. to be more accurate, faster, more economic etc. We have stated that improved performance has been the prime and the most direct motivation for the development.

Indeed, the performance has been greatly improved during the last 2 or 3 decades, in almost all aspects of photogrammetry. And the development tends to continue, even with acceleration, because the tools still become more powerful every day, especially the tools related to computer technology. This refers not only to computer hardware but also implies the conceptual development in software engineering and in computer science.

Whilst acknowledging the great effects of technical development in photogrammetry, we also realize that there is still more to it than improved technical performance. The review in chapter 2 has touched several times cases where deep structural changes were associated with the development which went much beyond the original intention or anticipation. As soon as the technical problems of a development step are solved, there seems a certain explosion to take place. Tasks come within reach which lie beyond the original scope. The power of the tools seems to push a development into new methods and into new thematic expansion, either by increased complexity and increased economic performance, or by the sheer new accessiblity of tasks which were previously out of reach and therefore out of concept. New equipment and new performance make old working methods obsolete, change them thorougly, and introduce new ones.

I want to draw the attention to the tendency which seems to reflect a certain inherent logic, that technical development and improved performance lead to an expansion of methods which

Photogrammetrische Woche 1991
Schriftenreihe, Heft 15, 1991
Institut für Photogrammetrie

create new possibilities. This in turn leads to new products, new concepts, new applications and thematic expansions. Such expansions seem to happen by themselves, out of inherent stringency, independent of whether they were anticipted, intended, or only vaguely envisaged.

In the following some selected cases are discussed how developments have outgrown themselves into new structures.

3.2 Some examples

3.2.1 Analytical and digital point determination

Analytical and digital point determination started about 25 yers ago by the development of computational block adjustment. It was the combined result of computer programming and general theoretical concepts. It is forgotten today, that there was a long struggle about the sound theoretical approach and the adequate solution methods. It was the first attempt in geodesy and surveying to solve large adjustment problems with thousands of unknowns on the basis of very limited computer capacity. However, as soon as reasonably general solutions had been developed and had become available on the computers of the time, there was a quick breakthrough into successfull practical application. The anticipated effects worked out very well. Block adjustment became standard, the accuracy was improved, the control requirements reduced. The method successfully pushed aerial triangulation on a new level of performance.

However, it soon became evident that the development and application of analytical aerial triangulation showed results and consequences and displayed features which went very much beyond the direct improvement of technical performance and which had not previously been foreseen nor planned for.
Aerial triangulation suddenly became a clearly structured system, composed of separate modules (point transfer, measurements, data reduction, adjustment). The result was not only improved economy. The system also became highly predictable with regard to accuracy, time and costs. It is now one of the best predictable operations in photogrammetry.
The great simplification effects of a sound general solution had severe consequences also in other directions. The famous first-order stereo-plotters which were the pride of photogrammetric industry and which had been particularly designed for strip triangulation, suddenly disappeared completely at the beginning of the 1970s. Instrumental strip formation was not required anymore, being replaced by computational connection of stereo-models or of bundles of rays. In the same sweep strip triangulation and strip adjustment disappeared as separate methods. And radial triangulation left the scene for good.

Another block of unforeseen consequences of analytical aerial triangulation concerns extended fields of application. The background is the unexpected high accuracy which can be reached, in case signalized points are used. It has boosted block triangulation to the level of a genuine, high precision, geodetic point determination method. Photogrammetric block triangulation has been successfully applied for high precision (1,5 cm level) point determination for cadastral purposes. It has also been successfully applied for geodetic network densification, and for the geodetic triangulation of parts of the moon. The term 'photogeodesy' describes the field of operation. Unfortunately, geodetic competition has prevented general application. Nevertheless, it is essential for our line of reasoning to see that the accuracy performance of photo-triangulation has made it a geodetic point determination method in its own right which has grown beyond the original internal application of providing ground control for photogrammetric mapping.

In a very similar way photo-triangulation has outgrown itself in the application to close range and to industrial photogrammetry in particular. In that field of application - simultaneously orienting photographs and deriving surfaces and shapes of industrial objects or products by point determination - analytical photogrammetry has been pushed to its highest accuracy performance and has opened up new applications. It is not exaggerated to say that the modern boom in close range photogrammetry is based entirely on the achievement of analytical methods.

Another package of development in aerial triangulation can be identified which has matured into more general theorectical concepts and progressed accordingly towards wider scopes of performance. We refer to block adjustment methods with extended capabilities for auxiliary data, external constraints,selfcalibration, and automatic blunder detection. Those items seem to represent mere extensions to existing block adjustment computer programs. In reality, however, they constitute principal conceptual steps, on a completely new theoretical level, of great practical importance, which have previously been outside any conceivable form of realisation. We touch here the highly intricate philosophical question of the interaction of advanced theoretical concepts and the technical possibilities of transferring them into practical application.

The latest extension of aerial triangulation concerns the introduction of GPS camera position data into combined block adjustment. Technically it is nothing new at all, just including auxiliary positioning data into the block adjustment in the same way as statscope data used to be handled. The high accuracy of GPS positioning, however, creates a revolutionary new situation, by making aerial triangulation almost independent of ground control. In addition, it is conceivable that in future also camera attitude data may be measured directly, with sufficient accuracy. Then aerial triangulation as a system may become obsolete, one day, at least for low accuracy applications.

Those examples may suffice to demonstrate that the relatively simple concepts at the beginning of analytical aerial triangulation not only have pushed the technical and economic performance of the method tremendously. In addition they have grown into new and extended application. Today we operate in photo-triangulation on a completely different methodical level. Our views and concepts have changed fundamentally which could not have been anticipated 20 years ago.

Still, there is another step to come, which can totally change the scene again. Switching to digital photogrammetry automatic photo-triangulation will become possible, based on automatic digital point transfer and point measurement. The result will be high accuracy aerial triangulation, also in standard cases, and high economy, especially also in combination with GPS camera positioning. The complete aerial triangulation will be a batch process, human operator functions being restricted to monitoring and checking functions.

3.2.2 Digital elevation models and derived products

We witness a similar system development, which has vastly outgrown the original concept, in the field of digital elevation models. After a prelude related to planning of highway construction digital elevation models came into general photogrammetry about 20 years ago. At that time they were intended for the automatic derivation and plotting of contour lines by computational means. We remember the furious opposition from the cartographic side against the idea. After some struggling, however, the DEM was able to prove its capability to computationally produce high quality contour lines. In addition, and much beyond the original concept, the DEM established itself as a new base product, suited for the era of digital information systems. It is understood, today, that all national survey departments are supposed to issue DEMs officially, in the same way as contour maps have been published describing the topography of a country.

The technical photogrammetric and computational methods of deriving digital elevating models have not only established the DEM as an independent high quality product, which can constitute a layer in a Geographical Information System. In addition, the DEM also has gained a central function with regard to a whole hierarchy of follow-up products which are derived from it, such as contour lines, digital slope models, slope maps, exposition maps, visibility maps, perspective views on topography, hill shading etc.

Again it is evident that the present function and importance of the DEM is much more than we had in mind at the beginning, when struggling with the problems of DEM interpolation and of deriving high quality contour lines.

3.2.3 From digital maps to Geographic Information Systems

It has been described that the conventional photogrammetric mapping process has gone digital via digital object capture from aerial photographs, and that digital data bases have started to replace graphical mapping as primary goal. In both cases the interactive graphical workstations have become the essential tool for efficient, versatile and comfortable execution.

With the concept of digital data bases the connection has been established with the world of geographic information systems (GIS). Information systems have been developed outside photogrammetry and surveying, although the land information systems (LIS) had a share in it. There are various and close relationships with photogrammetry, especially in the form of digital object capture and object modelling, for topographic data bases. What has started as digital mapping in photogrammetry, making use of computational tools and methods, now finds itself embedded and integrated in a much wider system. In that process the mapping aspect, which was primary at the beginning, has been pushed into the background, being only one - perhaps the most important one - of the display functions in GIS. And via GIS the whole range of geocoded mapping is at our disposal, including the various kinds of thematic maps, which combine and present thematic information on a topographical base.

Thus again, like with DEM, the technical side of digital mapping has been the stepping stone for development and integration into data bases in the much wider context of GIS, with entirely new aspects of interfacing different kinds of data and of information, and with expanded fields of application.

3.2.4 Image processing, image analysis, image understanding

The review of digital image processing has made clear that it is still in the research phase, as far as photogrammetric application is concerned, still struggling with technical problems and the handling of MBytes and GBytes of data. Nevertheless, some developments have reached a status that successful practical application can be envisaged. From the photogrammetric point of view especially the digital orthophoto and the image matching techniques applied to the automatic derivation of digital elevation models are of particular interest.

It can be anticipated that automatic surface reconstruction by image processing will again display features which imply much more than the mere technical solution to the problem. We have seen that automated car body measurement opens a gate for industrial photogrammetry.

The automatic derivation of digital terrain models by digital image processing is expected to boost DEMs to a new level of quality and to a new philosophy. Automatic derivation of DEMs can be very fast and provide a much denser grid representation of the terrain. Hence they can be considerably more precise. In addition, automatic measurement of breaklines is possible, as well as automatic elimination of 3D disturbancies of the terrain surface. The overall result will certainly be a new status and extended application of digital elevation models, although only well established techniques are applied.

It is tempting to speculate here on the effects which the high level image processing functions will have, if sooner or later pattern recognition, semantic modelling, knowledge based image understanding and image interpretation will have reached a level of development which will allow increasingly demanding application. However, it is too early to go into it, here. But the direction of development has been set, and the first successful steps concerning automatic object recognition and object extraction have been taken.

3.2.5 Realtime photogrammetry

The last example of how technical developments inevitably entail results on a more general level concerns CCD cameras. They have been mentioned to become available and to have some application in close range photogrammetry, for the time being. Their appearance can be seen as a necessary logical premise to establish digital photogrammetry. They cannot yet compete with established photogrammetric cameras. Nevertheless, first photogrammetric applications are being worked out, taking advantage of the direct access to digital image data.

Digital cameras offer one particular aspect which is new in photogrammetry and may give photogrammetry a totally new quality. It is the potential realtime capability. Digital cameras open the path, in principle, to realtime or, at least, to near realtime photogrammetry. It is beyond our present imagination to envisage the performance and the potential application of digital image capture and image processing more or less in realtime. There are still quite some technical problems to be solved. It is certain, however, that a technically successful solution of realtime digital photogrammetry would mean a total breakthrough. It could thrust photogrammetry into industrial application to an extent which, in my opinion, might eventually supersede the conventional topographical application.

3.3 Structural changes

The review of milestone developments and the discussed examples have sufficiently demonstrated that we have had great technical development in photogrammetry during the past 2 or 3 decades. It has also been demonstrated that, through and beyond the technical aspects, the development has also entailed a great evolution of methods, of products and of application. The resulting changes have been most thorough, touching partly the fundamentals of our work. Photogrammetry today is completely different from what it was 20 or 30 years ago. In other words, it has undergone thorough structural changes, with respect to the tools, the type and performance of the results, and the fields of application. There are basic structural changes in several aspects:

- There has been a total switch to computerized methods, software operations, and digital results. It represents a new approach to photogrammetry. What a change of paradigm, if compared with the world in which photogrammetry used to be the art of avoiding computation!

Photogrammetrische Woche 1991
Schriftenreihe, Heft 15, 1991
Institut für Photogrammetrie

- Point determination has become a closed operational block within photogrammetry. Methods of high theoretical standards are applied, resulting in geodetic quality standards. Because of it, photogrammetry has moved out from the corner where it had been framed as 4th order or 5th order geodesy.
- Photogrammetric mapping has gone digital, and it has exchanged its status with digital data bases, becoming part of geographical information systems.
- There is a clear tendency towards automation in photogrammetry, implying black box philosophy of operations. Also, the human operator will be released more and more from measuring functions, in favour of high level monitoring functions and quality control.
- With digital cameras and digital image processing photogrammetry will operate in a completely different environment, characterized by different equipment, techniques, skills, and by a different way of thinking.
- Photogrammetry has become more flexible, moving away from standard procedures, standard products, and fixed routine operations.
- Computer software has caused a certain convergence of working methods. The previous subdivisions in small and fixed procedures has been replaced by computer methods which represent more general solutions for larger operational units.
- Also, the industrial scene has changed considerably. There was not only some shake-up in established industry, also the fixation on optical mechanical craftsmanship has been opened for electronics as well as for computer- and software-based system design. In addition, a great number of software companies offer service, tools, and products, satisfying needs which had previously not existed.

4. Interfacing with other Disciplines

The development in photogrammetry and the resulting structural changes have been considered up to here, with regard to the established contents and the internal structures of photogrammetry. Looking now briefly at the external aspects of photogrammetry we notice immediately that there also are structural changes going on which appear to be even more radical than within the system.

We have already touched the new dimensions photogrammetry moves into with regard to GIS, industrial application and image processing. We can add here the expected convergence of photogrammetry and remote sensing into a wider unit. In those fields new quality and new types of products are being offered. The products are not any more specified and restricted to the closed world of surveying and mapping. Instead, the discipline opens itself for extended services, extended products, extended user communities. With regard to GIS, for instance, we can state that

- we offer environmental data and information, instead of mere topographic maps
- our type of information is to be interfaced with other classes of information (thematic, physical, administrative, legal, etc.)
- the potential user community is diversified and very large.

Similar statements could be formulated for the other fields of operation of photogrammetry.

There is no doubt that photogrammetry - as a result of vastly improved performance and extended products - is moving into an extended range of application, outgrowing (and growing with) the hitherto closed field of surveying and mapping. On the other hand we have seen that our work depends more than ever on conditions and progress of technology and of computer science. Thus, we have the general situation that photogrammetry will be interfaced and integrated with neighbouring disciplines and user groups much more than up to now, rendering more and better services and products than ever before. This implies, however, that also the competition with other disciplines will be harder, at the same time, as we have no fields reserved for us. Information systems and image analysis are the playgrounds of several disciplines.

The chances are quite good, in my opinion, for photogrammetry to establish and maintain itself on the new scenario of competition. I have tried to show - and this closes the circle and brings us back to the starting point - that the evolution of photogrammetry and its far reaching structural changes are related by inherent consistency with the technical progress which constitutes the platform for new and extended possibilities. Thus it remains our prime task, within photogrammetry, to keep exploiting the scientific and technical progress and to make our working methods as precise, efficient, reliable and generally applicable as possible, making maximum use of computer technology and computer science.

5. Outlook, new challenge

It is not intended nor possible to sketch here the future development. A few conclusions can briefly be drawn, however.

The interdisciplinary aspects will certainly become stronger, as the extended performance development will continue. The structural changes are likely to still go deeper. Photogrammetry (and the whole survey world) will have to re-orient itself. Established organisational and professional structures might crumble before re-emerging in new shape. Our professional and scientific education will have to draw consequences, and required expert skills and fields of competence will be quite different from now. Also, we might expect certain shake-ups in and of organisations.

Personally I am not much worried about such prospects. They reflect general conditions of today's world and are not in any way specific for us. Much more important are the great and truly fantastic prospects of photogrammetry. We have every reason to anticipate further development and great extension of our discipline. The future is a great challenge in first instance, asking for enthusiastic engagement.

I feel reminded of the situation we were in more than 20 years ago. At the occasion of the Otto-von-Gruber memorial lecture, delivered at the Photogrammetric Week in Karlsruhe 1967, I then talked about the great impact which computer methods in photogrammetry and surveying would have, the power they would display, and the new operational level of performance which would be reached. Referring to a remark which I must have made, when commenting the new challenge, the local newspaper on the following day summarized my appeal with the headline: 'The romantic times are gone'. In looking back that statemented turned out to be true, in a way. The fact did not prevent us, however, from enthusiastically participating in the development and driving it hard. Thus, once again, we may expectantly face and enjoy the challenge of the new style romanticism.

Zusammenfassung

Es wird eine Übersicht über die wichtigsten neueren Entwicklungen in der Photogrammetrie gegeben, die auf den Fortschritten in der Elektronik, der Computer-Technologie sowie der Computer-Verfahren und der Informatik beruhen.

Die technische Leistungssteigerung hat zu einer methodischen und thematischen Ausweitung sowie zu tiefgreifenden strukturellen Veränderungen der Photogrammetrie geführt, wie an hand einiger Beispiele aufgezeigt wird. Die allgemeine Bedeutung digitaler Ergebnisse bringt die Photogrammetrie auf eine neue Produkt- und Leistungsebene und führt über die bisherigen Anwendungen hinaus zur Integration bzw. auch zur Konkurrenz mit Nachbardisziplinen, vor allem auf den Gebieten der geographischen Informationssysteme und der digitalen Bildverarbeitung.

Als Ausblick werden auf der Basis fortgesetzter Leistungssteigerung weitere tiefgreifende strukturelle Änderungen erwartet, die auch erhebliche organisatorische und berufliche Folgerungen nach sich ziehen können, die aber leztlich als eine große neue Herausforderung aufzunehmen sind.

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