The Effect of Digital Photogrammetry on Existing Photogrammetric Concepts, Procedures and Systems

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Abstract

The transition from analog to analytical photogrammetry started some twenty years ago, and it is not yet complete, at least not in photogrammetric practice. And now a new transition, from analytical to digital, is emerging. This paper is concerned with those factors that will influence concepts and methods, perhaps even some aspects of the theory of photogrammetry. Digital photogrammetry not only attempts to duplicate existing analytical procedures, but also to automate processes normally performed by operators. A better understanding of such processes can be reached by employing methods from cognitive science and artificial intelligence. This efforts will ultimately augment the theory and elucidate concepts, thus providing the necessary groundwork on which attempts to automate human processes in photogrammetry should be based.

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1 Introduction

Digital photogrammetry is rapidly emerging as a new subfield of photogrammetry. As always when new technologies and methods develop, there is no unified terminology, let alone an accepted definition of digital photogrammetry and a clear distinction with related fields. Reports about the capabilities and benefits, perhaps not read and interpreted in the appropriate context, may push the expectations beyond what can be delivered in the foreseeable future.

On the occasion of the joint meeting of several working groups of ISP Commission II in Rockville, MD, 1986, three subgroups within Working Group II–6, *Integrated Photogrammetric Systems*, were formed. The author was asked to lead the group *Concepts and System Models*. This paper is in response to that assignment. It is a further discussion of [7], presented at the Symposium of Commission II in Baltimore. Inevitably linked with the emergence of new disciplines and methods, such as digital photogrammetry, is a strong temptation to apply them without a clear concept. More efforts should be undertaken to augment the theory and to elucidate concepts. Hence it is hoped, that the activities of the group *Concepts and System Models* will be carried on.

The purpose of the paper is to comment on the effect of digital photogrammetry on existing concepts, on issues in research and development, followed by an attempt to predict the effect on users. In order to differentiate digital photogrammetry from other fields, such as analytical and computer-assisted photogrammetry, some background information is summarized in the next section. A brief description of the problems in digital photogrammetry and an assessment of where we are is interjected before the effects on research, development and on users are described. Predicting developments is a matter of extrapolating from known facts obtained in the past and the present. It is a subjective process; opinions and conclusions expressed in this paper are personal, they should not be regarded as an official consensus of Working Group II-6.

2 Background

The development of photogrammetry is closely correlated with the general development of science and technology.This, in turn, may even be seen as coupled with the world economy, which, according to one theory, evolves in waves. Konecny in [5] draws an interesting parallel between that theory and the development in photogrammetry. As pointed out by several authors, see for example [1,8], the invention of photography, airplanes and computers brought about new generations in photogrammetry.

Photogrammetry had its beginning with the invention of photography. The first generation, from the middle to the end of last century, was very much a pioneering and experimental phase with remarkable achievements in terrestrial photogrammetry.

The second generation is characterized by the invention of stereophotogrammetry. Airplanes and cameras became operational during the first world war. Between the two world wars, the main foundations of aerial survey techniques were built and they stand until today. Analog rectification and stereoplotting instruments became widely available. Photogrammetry established itself as an efficient surveying and mapping method. The basic mathematical theory was known, but the amount of computation was prohibitive for numerical solutions and consequently all the efforts were aimed toward analog methods,

Generation	Hardware	Software	Photogrammetric Disciplines
1^{st}	- vacuum tubes	- machine code	*analytical photogrammetry* - aerotriangulation - correlation - analytical plotter
2^{nd}	- transistors - magnetic core memory	- higher level languages (FORTRAN, COBOL)	
3^{rd}	- IC memory - minicomputers - magn. disk storage	- time sharing - operating systems - virtual memory	
4^{th}	- microprocessors, PC - VLSI - networking	- new languages (PASCAL, MODULA) - IGS, DBMS	*computer-assisted photogrammetry*
5^{th}	- parallel processing - RISC architecture - VHSIC - optical disk storage	- knowledge based SW - expert systems - natural language processing	*digital photogrammetry* - real-time photogrammetry

Table 1: Computer generations and new photogrammetric disciplines

hence the name *Analog Photogrammetry* for this epoch.
With the advent of the computer, the third generation has begun, under the motto *Analytical Photogrammetry.* Table 1 provides an overview of computer generations and new photogrammetric disciplines that originated from the development of computer science. Among the photogrammetrists who had first access to computers was Helmut Schmid, who developed the basis for analytical photogrammetry in the fifties. Many others refined and complemented the theory. Great strides have been made in the last thirty years. Several well proven methods are available, block adjustment may include additional parameters, self-calibration, elegant methods for gross error detection and so forth. There are not very many problems of importance left in analytical photogrammetry.

Other achievements of this period are the invention of the analytical plotter by Helava and correlation by Hobrough. It is interesting to point out the time elapsed from the moment of an invention until it becomes operational and available to the photogrammetric practice. The first operational aerotriangulation programs became available in the late sixties (Ackermann, Brown, van den Hout, Schut), and it took another decade before aerotriangulation was widely used by photogrammetrists. A similar observation can be made for analytical plotters: the time gap between its invention and wide spread use is nearly thirty years.
What factors account for these remarkable time gaps? A number of organizations are involved in the transition of an invention to a robust, commercial available product. Inventions are likely to be associated with research organizations, such as universities, research institutes and the research departments of industry. The development of a product based on such research results is a second phase and is carried out, for example, by companies manufacturing photogrammetric equipment. The most important partner in the chain is the photogrammetrist: he daily uses the instruments and methods and gives valuable feedback to researchers and developers. Applied research should always have the open issues in mind, which are raised explicitly by the practising photogrammetrist. Comparing existing methods and solutions with the state-of-the-art technology and new results offered by other disciplines may also influence applied research. When predict-

ing the impact that digital photogrammetry will have on photogrammetric practice, it is advisable to remember these cycles and the associated time gaps.
Another remarkable event began in the early seventies when electronic plotting tables became available. In conjunction with interactive graphic techniques (IGS) map compilation was revolutionized in terms of throughput time and flexibility in the final product (hardcopy and softcopy). This is what we may call *computer-assisted photogrammetry* today. It is distinct from digital photogrammetry even though many authors use the two terms interchangeably. The notion of digital photogrammetry stems from using digital imagery instead of (aerial) photographs. The decisive factor is the kind of input material and not the output. Although the result of computer-assisted photogrammetry is a digital map, we should not be misled and call this digital photogrammetry.

3 Digital Photogrammetry

Digital photogrammetry has its root in the fifties when Hobrough began experimenting with correlation, even though the solutions were analog in nature. For almost twenty years correlation remained the only noticeable activity in digital photogrammetry. Research activities were revitalized a few years ago when digital cameras, image processing components and increased computing power became available. Interestingly enough, early satellite imagery, such as Landsat, did not spark much research interest in photogrammetry.
For lack of an accepted terminology we may question what characterizes digital photogrammetry. One criterion was already mentioned: the input is digital imagery. That is, an image (photograph) is stored in digital form suitable to be accessed by computers. It is irrelevant whether the image was directly acquired in digital form (e.g. SPOT, CCD cameras), or indirectly, for example by digitizing photographs. A second criterion for digital photogrammetry is processing digital imagery by computers, be it interactively or automatically, without an operator's intervention. This statement can be broadly interpreted as there is no concensus on how far the computer must carry out subsequent processes. An example may illustrate the case. Suppose a digitized stereopair is displayed on two monitors and viewed stereoscopically, employing one of the three-dimensional viewing techniques. The operator uses a cursor, like the floating mark of an analytical plotter, to identify points and features whose image coordinates are then recorded. Model or object coordinates can easily be computed, again similar to analytical plotters. If the only process consisted of displaying the digital imagery and straight forward methods from analytical photogrammetry are then applied, do we call this digital photogrammetry?

4 Problems in Digital Photogrammetry

Since digital photogrammetry is in its infancy it is easy to generate an impressive list of problems. In fact, virtually every task is an unsolved problem. In some aspects, the present state can be compared with analog photogrammetry in the thirties or with analytical photogrammetry in the sixties. Even though digital frame cameras with resolutions of 1024 by 1024 pixels are now becoming available, they still fall short by an order of magnitude compared with the resolution of aerial cameras. The information content of an aerial photograph is approximately one to two gigabytes (GB), that is, just about the storage capacity of a twelve-inch optical disk. However, photogrammetric projects may involve hundreds of photographs. As of today, there is no sensible way to effectively store, retrieve and process this magnitude of data.

This is not said to down-play digital photogrammetry. On the contrary, research efforts, mostly focused on close-range applications, are beginning to bear fruit and before long we shall see photogrammetrists using digital systems for special applications.

Research efforts in digital photogrammetry are mostly aimed at data acquisition and determining positions of points. Gruen [3] gives an account of problems related to acquiring imagery of metric quality. Once we have a good grasp of all of the factors influencing the geometry of the image space, reliable image coordinates will be available and methods of analytical photogrammetry can be used to determine accurate positions in the object space or establish digital elevation models (DEM), automatically, of course. All subsequent processes are known, and it is indeed tempting to predict that an "automatic stereooperator" (see [8]) will then soon take over.

Most of the tasks that human operators perform with great ease are very difficult to solve by computers. Fusing together two corresponding image patches to a three-dimensional object is something we do without conscious effort. Despite impressive computer solutions we are not near the human capabilities of seing stereoscopically — a fundamental task in photogrammetry. If we do not want to restrict digital photogrammetry to narrowly defined applications, such as determining points in a controlled environment, we need to address the problem of interpreting the model space by identifying objects and extracting features. Image understanding is hardly ever looked at by photogrammetrists, probably because we are so entrenched in the micron and sub-pixel world, deeply if not exclusively concerned with accurate point positioning. However, the final product of map compilation, for example, does not only consist of points. Equally important is the semantic information. As we move from paper maps to "digital" maps and information systems, the aspect of the semantic description accompanying the geometrical description of the object space becomes paramount.

What is involved? At the outset is digital imagery of some sort. We ultimately expect from digital photogrammetry that the input be converted to an accurate, intelligent description of the object space that may form the base of an information system, such as a geographic information systems (GIS). An aerial photograph renders approximately two GB of data while a map covering the same area is more in the range of KB. Therefore one aspect of digital photogrammetry is data reduction which is closely related to another fundamental difference between digital imagery and GIS, namely the way in which information is represented. In a GIS (or on maps), information is represented explicitly, while in photographs information is implicit — it is "buried" in the pixels. Hence, another aspect is extracting information, making it explicit.

Figure 1 depicts the aspect of data reduction and the increase in explicitness of information, beginning from raw digital imagery to a fully interpreted information system. The tasks involved are normally grouped in low level and high level processes. Point positioning and DEM are low level tasks.

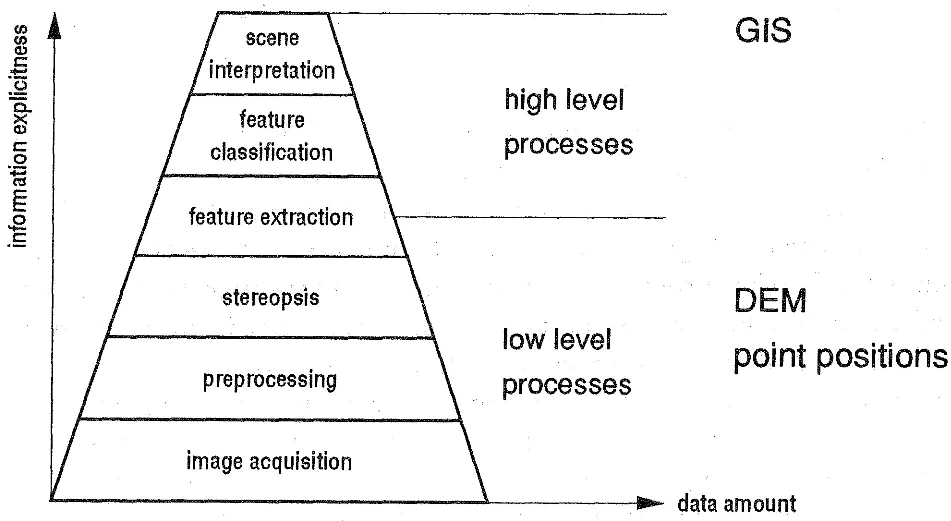

Figure 1: Major tasks of digital photogrammetry from raw digital imagery to an interpreted scene (GIS)

5 Effects of Digital Photogrammetry

In this section, the effects of digital photogrammetry on research, manufacturers and users are discussed.

5.1 Effects on Research

The main thrust of research in photogrammetry is expected to shift from analytical to digital. Data acquisition and special applications, most likely in close-range photogrammetry, are of prime interest (see e.g. [3,8]). Recently held workshops and symposia, such as *Real-Time Photogrammetry – A New Challenge, 1986* or *ISPRS Intercommission Conference on "Fast Processing of Photogrammetric Data," 1987* are evidence of increased activities in this field.

Other research activities are concerned with extracting features from digital imagery and interpreting the object space. This area, broadly termed image understanding, is much neglected by photogrammetrists. It lies more in the mainstream of research interest in computer vision and artificial intelligence. There are a number of reasons, however, for photogrammetrists to embark on these research areas. Foremost, we have the application know-how. We are the experts when it comes to precisely analyzing how photogrammetric models are compiled. But how much do we really know? Apparently not enough, otherwise we should be able to instruct a machine how to do compile a model. This conclusion, which seems a contradiction in terms, needs further clarification.

The different tasks in photogrammetry can coarsely be divided into two classes if compared with the degree of difficulty to solve them by computers. One class contains solvable problems (problems in analytical photogrammetry, such as aerotriangulation, orientation, etc.). The second class of tasks are very difficult to solve by computers (map compilation, for example). Interestingly enough, the first class looks by far more difficult, while it is easier to explain the second class of problems to a lay public — indeed a paradoxic situation. Not necesserily so in artificial intelligence: if we go by Riche's definition ... *the* *study of how to make computers do things at which, at the moment, people are better* (see [6]).

The instructions to an operator are relatively concise, they may even be ambiguous and incomplete, because he or she has enough knowledge and common sense to solve the problem. On the other hand, for a computer to perform the same task requires a great deal more instructions, for lack of common sense or knowledge, unless it was put into the machine at an earlier stage. Hence, we must conclude that the theory of photogrammetry is incomplete. Further progress in automating photogrammetry depends on a precise understanding of how human operators solve problems. Artificial intelligence and cognitive science help to analyze these processes. Once understood, the theory will be more complete, models can be devised and appropriate algorithms be designed. This approach is in contrast to the popular method of trial and error: different methods and algorithms are tested until a satisfactory solution is found — only until it fails in the next application. Thus, the compelling conclusion is that digital photogrammetry forces us to complete the theory of photogrammetry.

5.2 Effects on Manufacturers

Before photogrammetrists can benefit from research results (or from a more complete theory), an important step has to be accomplished, namely, the development of research findings into reliable, commercially available products. A few companies have specialized in this area and have established a remarkable relationship with end users over many decades. For the last ten to fifteen years, when research results in analytical photogrammetry and new technologies for computer-assisted photogrammetry became available, the traditional manufacturers have had to endure major transitions. Although the transition from analog to analytical and computer-assisted photogrammetry has taken place, the change to digital photogrammetry is forthcoming. The accelerated shift from traditional hardware to computer, peripherals and software, are inevitably forcing a change in know-how. High precision mechanical/optical components will disappear as an all digital system will ultimately only consist of computer hardware, software and sensors. It remains to be seen whether manufacturers of classical photogrammetric instrumentation will have the upper hand over companies specializing in image processing, expert systems and machine vision. An interesting observation in this context: during the transition from analog to analytical, many "intruders" appeared on the market with analytical plotters, but none of them survived.

5.3 Effects on Users

Users are probably concerned with the question of when products of digital photogrammetry will be available. Or are there already products one should now acquire in order to have an edge over competitors? An answer may be given from historical considerations. The elapsed time between an invention or major research results becoming available to photogrammetric practice on a broad base was ten to twenty years in the past. Examples were mentioned in section two: for analytical plotters and aerotriangulation the time gap was more than twenty years and for computer-assisted photogrammetry ten to fifteen years. Will it be different for digital photogrammetry which is just beginning?

Another answer to this question may come from a survey of existing digital photogrammetry products. The ISPRS congress is always an excellent opportunity for assessing not only the present but also future oriented products. Not knowing what manufacturers will exhibit makes any statement a prediction. Apart from image processing systems with applications in remote sensing rather than photogrammetry, we may see "digital analytical plotters." If such systems will be as contradictory and questionable as the name, it will be an easy decision whether or not to buy immediately or to wait until a significant price performance ratio versus analytical plotters is reached. It should be mentioned that the inventor of the analytical plotter, Helava, already demonstrated a digital system with remarkable capabilities during the ASPRS spring convention, 1987 (see [4]).
An interesting aspect of digital photogrammetry is data acquisition. For certain close-range applications it may prove advantageous to have digital imagery available for immediate processing. That branch bears the appropriate name *real-time photogrammetry*. Products such as data acquisition with digital cameras, image processing hardware and software, and application software may soon be expected with potential to open up new application areas as in quality control in industry.

6 Conclusions, Prospects

Although digital photogrammetry has its root in the mid fifties when first experiments with correlation were carried out, major research activities began only a few years ago with the appearance of appropriate hardware, such as digital cameras and image processing components. Not surprisingly, the new discipline is in a constant state of flux that makes it difficult to distinguish between established research results, proven concepts, claims and available and supported products. In trying to assess the field it may help to draw analogies to similar developments in the past, for example analytical and computer- assisted photogrammetry. What are the "invariants" or the rules that govern the emergence of a new subfield? A typical cycle can be observed, initiated by research, followed by the development of products used in the photogrammetric practice, be it for performing existing tasks more efficiently or for tackling new applications. Related to all the phases is education, another prerequisite for the successful development and use of new methods and products. Associated with this are time gaps. In the case of analytical photogrammetry it is nearly thirty years between invention and wide spread use, and some fifteen years in the case of computer-assisted photogrammetry. The time gaps are likely to shorten, but there is no shortcut from research results (including experimental systems) to robust, well-proven and supported products.
Another observation can be made with respect to the difference between basic research and experiments. Examples may illustrate the difference and, more importantly, the consequences. The development and the success of analytical photogrammetry was driven by research, leading to a sound theory (mathematical model) based on which it was possible to design suitable algorithms for efficient solutions. Almost at the same time correlation began. However, the development of that field was based on experiments, on attempts to solve the problem by trial and error. The net result: despite considerable efforts over nearly thirty years, correlation is still not solved, no system exists that would determine DEM automatically, independent of scale, type of terrain and image quality.
At first glance it appears more difficult to develop a theory about aerotriangulation as

compared to develop a method of correlating two overlapping aerial photographs. Humans have no problem fusing two images together and forming a stereo model. We see stereoscopically without conscious effort, in real-time. Tasks readily performed by humans are difficult for computers to mimic because we lack of detailed enough knowledge. Digital photogrammetry addresses tasks that are presently performed by operators: seeing stereoscopically, orienting the stereopair, interpreting and measuring the stereomodel to compile a map. The point to be made here is that we should first understand thoroughly how these tasks are solved by human operators. Only then we can model the process (in analogy to develop a mathematical model), design algorithms and begin with experiments. Analyzing and understanding human tasks will only succeed when performed in an interdisciplinary environment. The concentrated effort of specialists in artificial intelligence, cognitive science, machine vision and possibly other fields promises success. It may be necessary to arrange for an inter disciplinary environment that accomodates researchers from different disciplines and provides an organizational structure. At The Ohio State University we have recently experienced very stimulating effects from such an organization. The Center for Mapping is an umbrella organization for a dozen different departments, providing facilities and research projects, (see [2]).

Progress in digital photogrammetry will come in stages. Systems that will allow determining points in "real-time" in controlled environment should appear on the market soon. Improvements in generating DEM automatically can also be expected in the forseeable future (based on new methods developed for stereovision). As indicated in Figure 1, these products belong to the class of low level vision. High level vision is basically concerned with extracting and classifying features and interpreting the object space. As these tasks are not well understood and basic research is continuing, predictions when products suitable for photogrammetric applications will become available, are afflicted with a high degree of uncertainty. It will presumably remain a research subject for decades. Partial success can be implemented in hybrid systems. That is, features extracted and classified are displayed on interactive workstations for the operator to supervise, to check, to correct and to complement the process.

Digital photogrammetry also poses a new challenge to education for students need be taught in that field too, to meet the demand arising from potential users, development and research. As digital photogrammetry draws from fields such as signal and image processing, computer vision, artificial intelligence, expert systems, cognitive science, adequate background information has to be provided. Because in reality analog, analytical and computer-assisted photogrammetry coexist, we cannot overload existing programs with a lot of new courses, nor can we easily drop courses. Digital photogrammetry will be an addition rather than a replacement.

Finally, it is strongly recommended to coordinate the increasing activities in digital photogrammetry, at least among the different ISPRS commissions and working groups. Because digital photogrammetry is closely related to and dependent on other disciplines such as computer vision, coordination should even be encouraged between respective organizations. Confusion and misunderstandings in terms of terminology, definitions and concepts could greatly be reduced — to the benefit of all.

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