PROSPECTS IN DIGITAL PHOTOGRAMMETRY

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ABSTRACT

Digital photogrammetry has reached a substantial degree of maturity. All its technical problems have been solved and brought to practice. Its workstations are affordable, and have the capabilities to produce all types of conventional photogrammetric products, as well as several new products -- some of them essentially automatically. Seamless digital orthophotographs covering large areas and preoriented stereomodels -- on optical disk or high resolution tape -- are just a couple of examples. These capabilities are expected to revolutionize the ways photogrammetry is practiced and its products used.

INTRODUCTION

During the past few decades, photogrammetry has grown tremendously as an art and a science, and become a dominant mapping tool all over the world. We have observed the rise -- and decline -- of "optical train" stereo plotters, the birth of analytical triangulation and block adjustment, and the ascent of analytical plotters to their current position as preferred photogrammetric instruments. Photogrammetric cameras have become highly advanced. They soar into space to map the moon and the earth from the highest possible vantage points. All in all, photogrammetry has served mankind well, in mapping and in industry, in the air and in space.

We are now witnessing the advent of a new era, that of Digital Photogrammetry. Its roots are in computer technology, computer imaging and analytical photogrammetry. I've heard it said that a digital photogrammetry workstation is a new type of analytical plotter. In a limited sense that may be so, but the concept of digital photogrammetry has much greater potential. It brings about a bigger revolution than any instrument or methodology development in photogrammetry up to now. When it is fully developed, its effects will be felt also in neighboring fields. Photogrammetry itself will be dramatically different.

In recent years, photogrammetry has established important strategic alliances with Remote Sensing and Geographic (or Geodetic) Information Systems (GIS). These must be recognized as alliances, not mergers. Photogrammetry's domain must be kept clearly defined and distinct. Failing that -- and it has happened, to varying degrees -- the role of photogrammetry tends to become fuzzy. It is up to us photogrammetrists to remember that photogrammetry's domain is measurement: photogrammetry is the guardian of accuracy and metric integrity. That is a role of fundamental importance; it provides the foundation on which the alliance can build its structures.

In this paper, I'll explain why I believe that digital photogrammetry could lead to a renaissance in our profession. The key issues are the accuracy, the permanence, the stability and the repeatability of digital processes. They permit the establishment of an accurate and "everlasting" mathematical relationship between pixels and the ground. This relationship permits the generation of special products, unique to digital photogrammetry. I'll describe such products and discuss their implications for the production and the use of photogrammetric information.

THE FUNDAMENTAL STRENGTH OF DIGITAL PHOTOGRAMMETRY

Digital photogrammetry has experienced tremendous technical progress in its half a dozen years of existence. Better understanding of technical problems involved in realizing workstations for digital photogrammetry is a part of that progress. Another part is the "free ride" the field has had from computer technology. Capabilities that, a few years ago, took expensive custom equipment to realize can now be obtained with "store-bought", modestly priced hardware. The result is that state-of-the-art workstations for digital photogrammetry are now low cost, highly automated and capable of doing everything the traditional photogrammetric instruments can do, and more. That "more" is why digital photogrammetry has such high potential.

Let's recognize the basics: Mankind will need, for a long time to come, <u>accurate</u> information about positions of things and features tures on the earth's surface. For that, accurate <u>measurements</u> must be made. Photogrammetry is the measurement tool "par excellence" for making those measurements, even in view of the GPS (Global Positioning System) and its inevitable decendants. <u>Digital</u> photogrammetry is even better. It is better for many esoteric reasons, but one stands out in this conjunction: Digital photogrammetry can establish an accurate and <u>everlasting mathematical relationship</u> between sensor pixels and the ground. The emphasis is on <u>everlasting</u>; once the math model and the values of its parameters have been fixed, the image and ground coordinates are tied together permanently. One set can be computed from the other, and the results are always the same. This is <u>not</u> the case when photographic film is used as the image carrier. The instability of the film and the mechanical imperfections of the measuring instruments prevent exact replication of results. The everlasting permanence makes it possible for digital photogrammetry to generate interesting special products. Also, new ways of organizing their production become possible. These topics are expanded upon below.

SPECIAL PRODUCTS

Digital mapping is advancing very rapidly. The rate of its progress has resulted in great confusion regarding the meaning and the content of several topical concepts, such as GIS, LIS, and AM/FM. Very costly mistakes have been made as a result of the promotional "hype" sometimes used in "selling" GISs. Our profession would do well to distance itself from the hype and the confusion. Our task is to build the foundation and make it available for whatever project, construct or data base that needs it. Here the "everlasting" math relations come into play. They allow photogrammetrists to preprocess images to a point where laymen can easily make accurate measurements based on their own interpretation of what they see on the images. The "laymen" may be experts in some other field, cartographers with no photogrammetric training, or true laymen. Advantages accrue to everybody, including the GIS community. In effect, the utility and availability of photogrammetric data bases are vastly increased.

One might argue that preprocessing takes photogrammetry out of information extraction. So it does. But it does not decrease the importance of photogrammetry, or the scope of the activities of those making their living from it. Quite the contrary: it will give photogrammetry an impetus to look into potential advantages and interesting challenges of sensors other than "photogrammetric" cameras. Digital cameras, which are certain to appear, are likely to be geometrically more intricate. The challenges include tightening, better understanding and efficient system implementation of math models, new and old. There are fascinating -- and profitable -- "rows to hoe" in the field of the emerging "new" photogrammetry.

The preprocessing concept has profound technical and organizational implications. It affects interfaces within the photogrammetric profession, and potentially changes the role in map making. Photogrammetrists of tomorrow will provide final map products and preprocess images for others to use. This change may be inevitable, due to the rapidly expanding use of map information on softcopy workstations. By helping others, we'll help ourselves. In the products discussions below, the role of the photogrammetrists as the preprocessors is taken for granted.

Orthophoto mosaics

The efficient production of virtually perfect digital orthophoto mosaics is now within the state of the art in photogrammetric mapping. The mosaics are geometrically continuous and radiometrically virtually seamless. A mosaic can cover a large area, such as a county, state or even a whole country. Any part of the mosaic can be brought up for use in a softcopy workstation virtually instantaneously. These workstations are in the hands of the users; the orthophoto mosaics are produced by photogrammetrists as "preprocessors".

Conceptually, one should regard the mosaics as 1:1 images cast in a map projection. Their pixels (or "groundels") are squares accurately positioned in the map projection. The size of the pixels is selected to reflect the economic importance of the area depicted, or specific needs arising from engineering or legal requirements. For example, a 1X1 m^2 "groundel" size might do for the rural part of a county, while 25x25 cm^2 size might be appropriate for its urban area.

For storage, the 1:1 images are divided into tiles of suitable size to minimize access time. The tiles are positionally indexed, e.g. as a quadtree. Mosaicked images of thousands of square kilometres can be stored on one optical disk when compression/decompression techniques are employed. An index map and numerous layers of cartographic information can be included on the same disk. The layer most intimately associated with the orthophoto mosaic is the Digital Terrain Model (DTM). DTM permits instant interpolation of elevations. A set of minified versions can be added, with a relatively minor penalty in storage requirement. Any part of the data set can be brought up and displayed on a workstation in a few seconds. The access can be by coordinates, or by pointing to the area of interest on the index map and successive minified images. A "jukebox" of disks increases the storage capacity manyfold, at the expense of somewhat longer access time.

Software for using the stored data is included on the disk(s). The amount and variety of software that can be included is virtually unlimited. Workstations can even boot from the disk. A typical software package permits the users to specify the area of interest; receive a display; do radiometric adjustments; measure 3-D coordinates, distances, volumes, etc.; extract features; call up cartographic layers, contours, profiles etc.; edit data, and record and print out the results of their work. The basic package can be expanded in various directions. An example is software for dewarping of (distorted) data from existing (old) maps to fit the (better) geometry of the orthophoto mosaic. Software aids for automatic extraction of features is likely to become economically significant. Software can be provided for production of oblique views of the terrain by combining image and DTM information. At an extreme, a full GIS might be included, if desired.

Digital stereomate

The digital stereomate is a complement to digital orthophoto. For the exploitation of stereomates, the workstation must have stereo capability. The software used for orthophoto mosaics is expanded to include an elevation measuring capability. A DTM may be provided with the software package, or generated from the stereomate.

The stereomates can be generated in a natural or artificial form. In the natural form, the stereo information is taken from the second image of the stereo pair. In the artificial form, the image information is taken from the orthophoto and shifted to produce the stereo effect. The natural stereomates must be produced model-by-model to keep the direction of the actual stereo base. They retain the microrelief. They cannot be mosaicked, but many models can be stored on a single disk. Switching from model to model is almost instantaneous. The direction of the stereo base can be freely chosen for artificial stereomates, e.g. West to East. The "base-to-height ratio" can also be chosen. This type of stereomate can be generated a priori for the entire area covered by the associated orthophoto mosaic and stored with it. Alternatively, a local stereomate could be generated on-line, based on existing DTM. At the time of this writing, workstations capable of doing that in a reasonable time are quite expensive.

Preprocessed stereo models

Once all the parameters in the math model are available -- usually when triangulation has been completed -- the images can be used to extract metric information. The extraction can proceed directly, if the available workstation has enough power to handle the necessary computations in real time. Currently, such workstations are very expensive. Fortunately, a stepwise solution is workable. In this solution, the images are preprocessed to some desirable degree using less computing power, but more time*. One desirable degree assures ideal stereoviewing conditions by converting the images, model-by-model, into epipolar configurations. Some filtering and radiometric balancing is added, also. Mapping data can then be extracted using much less expensive workstations.With software, such workstations can be made to behave like "digital analytical plotters". Both elevation and feature extractions would be done manually. The images are preprocessed in stereo pairs and recorded on optical disk or high capacity tape. Numerous models fit on one disk or tape.

Another desirable degree of preprocessing is a complete geometric "rectification" or "dewarping". The objective is to return the images to the classical "normal case" of photogrammetry, so as to stardardize the real-time math model to a very basic level. The workstation can be very inexpensive, and the user need not know any photogrammetry.

A comprehensive applications software package can be included on the image tape or disk. The photogrammetric part may be hidden from the user; the math model and all its parameter values are entered automatically. The model shows up on the display fully "oriented" and ready for measurement. Automatic feature extraction aids can be provided. Theoretically, software packages could be provided for automatic DTM generation and editing. The use of

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*Foofnote: An inexpensive workstation can be implemented by doing the image processing in the background for the next window, while doing data extraction in the present one. However, this requires strict discipline in organizing the work.

these packages, however, would require considerable training of the "laymen". DTM generation is best included in the preprocessing performed by photogrammetric professionals.

Digital World Image

Digital World Image (DWI) may never become a "product", but the concept is intriguing in that it could provide a storage paradigm for all cartographic and geocoded information. In principle, DWI is a world wide digital orthophoto with its pixels defined in geographic coordinates (latitude and longitude). In terms of these coordinates, the pixel size can be constant in latitude, but must vary in longitude to maintain square pixels of more or less constant area coverage. Square pixels are desirable for simplicity of resampling and other algorithms. This restriction can disappear as readily available computer power increases. Since tiling is necessary for convenient access, a suitable longitudinal pixel spacing could be determined, and accepted "by definition", for each tile. The ground footprint of pixel would be approximately trapezoidal, but the effect of that in symmetrical pixel displays need not be too disturbing. All measurements, of course, can be corrected. Furthermore, square pixels in a map projection could be resampled and displayed, if necessary.

The intriguing characteristic of the DWI is that it could serve as the storage format for all imagery and other rasterized information. Conceivably, all kinds of imagery could be stored in this "everlasting" format. The original images could be discarded. Data from different sensors would then be accessible through the same addressing; it would be automatically registered, as precisely as permitted by processing accuracies. Points, vectors, and DTMs fit into the geographic coordinate system without problems, too. Gradually, a multispectral, multisensor, multitemporal database with registered DTMs and cartographic graphics would become available over the most important parts of the world, perhaps eventually over the entire earth.

PRODUCTION CONSIDERATIONS

Photogrammetry, like other professions, has always had some differentiations in the skills of its practitioners. In analog photogrammetry, the skill of achieving best possible orientation was held in high esteem, while in compilation, distinction was often based on the "order" of the instrument the photogrammetrist was able to operate. Currently, mastering the intricacies of analytical block adjustment often leads to specialization serving those doing primarily compilation on analytical plotters. Such distinctions notwithstanding, the production is usually highly integrated. In general, one close-knit organization handles the mapping project from the establishment of ground control to the final cartographic embellishment of the product.

The capability to use maps in softcopy form and to produce them by digital image photogrammetry presents a powerful force for change in the organization of photogrammetric production. Two of these are particularly forceful: the evident usefulness of bringing preprocessed digital products directly to the end user, and the high skill and cost requirements for efficient preprocessing.

The desirability of bringing preprocessed products directly to the end user has been hinted at in the preceeding paragraphs. The reason for the desirability is that maps, as we know them today, will become less and less necessary for many of their current uses. In many applications, maps become "ad hoc", dynamic, transitory and interactive addenda built on the photogrammetric foundation. Take a landscape architect or a real estate developer as examples. Technology is already in place for near real-time generation of perspective views based on a photogrammetric stereo model. The user can inspect the terrain from different vantage points, insert roads, trees, houses, etc., and even specify sun angles to see where the shadows fall. A map might be printed out for implementing the resulting design but, more likely, the landscapers and builders will display it on their portable workstations. Similar scenarios can be visualized for numerous other applications -- e.g. for populating GIS/LIS databases. Common features are the <u>primacy</u> of accurate photogrammetric foundations, data extraction and manipulation by the end user, and the demise of graphical maps as end products. Thus, a strong "demand pull" for preprocessed products is likely to develop in the coming years.

There are technological and economic reasons for the evolution toward preprocessing arrangements, even when the data extraction is done by photogrammetric/cartographic experts. The primary technical reason is the status of automation in photogrammetry. Currently, digital techniques permit the efficient automation of virtually everything, except feature extraction. Proper exploitation of present automation capability requires high professional skill and a relatively large investment in hardware and software. Photogrammetric facilities must permit accurate digitization; triangulation; DTM generation and editing; orthophoto production and mosaicking, and the performance of numerous ancillary tasks. With appropriate hardware, software and operator skills, the production efficiency can be high and cost per product low, despite the high cost of facilities. On the contrary, the feature extraction workstation may cost very little, even nothing, when the user happens to have available a powerful personal computer or a suitable GIS/LIS workstation. The comprehensive automation of feature extraction is not in sight, even if great computer power is a given. It might never be, because of the judgemental selectivity inherent in data extraction for various purposes. The required judgement may, or may not, be photogrammetric/cartographic. This suggests separation of feature extraction from other processes, thus strengthening arguments for preprocessing. Fortunately and fortuitously, the same dividing line applies to efficient automation. Thus, those equipped with an automation capability are likely to provide a "supply push" toward preprocessing.

CONCLUDING WORDS

Several profound revolutions -- technical and societal -- have taken place during the past few decades. Their full consequences are unpredictable. (See what happened in the U.S.S.R.!) Nevertheless, it does not appear too risky to predict that, in ten years, most professional use of map information will be in digital workstations. There will be elaborate applications programs and huge databases available in offices of engineers, planners, administrators and other professional users. Lightweight portable "workstations" can be taken to the field for interactive interfacing with the real world. The foundation of the databases could -- indeed should -- come from products of digital photogrammetry, such as those described above.