RUNNING BOTH ANALYTICAL AND DIGITAL PHOTOGRAMMETRIC PRODUCTION LINES IN A MAPPING ENVIRONMENT

Xiaopeng Li
Photogrammetric Application Specialist
A. Bruce Baker
Technology Manager
Intermap Technologies Corp., CANADA
xli@intermap.ca
bbaker@intermap.ca

Working Group II/7

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ABSTRACT

Today s mapping technologies are in the midst of transition, from analog and analytical to digital. The move to digital is being driven by the desire to increase production capability through computer automation and take advantage of new methods, procedures and technologies. During this transition two or more production lines may be run simultaneously with all the associated complexities. The mapping production environment is thus becoming increasingly complex. In the past there have been many successful introductions and changeovers of technology where the new, typically over a period of time, replaced the old. Is this truly the case for the current move to digital? This paper will present various aspects of running both digital and analytical photogrammetric mapping production lines in a modern mapping company.

1 INTRODUCTION

The situation of current photogrammetric mapping world can be described as *Many things are new*. *Many things are changing*. The latest advancement is digital softcopy photogrammetry which radically alters the instrumentation and procedures employed, the personnel and clientele involved (Derenyi, 1995). Mapping technologies are changing rapidly as the result of the advancement of related fields and the requirements of spatial information user society. In the recent past, static, fixed scale, multi use, highly accurate, permanent, paper maps compiled over a short period of time was the norm. Today s world uses a dynamic, single use, variable accuracy, variable scale, digital product made from data possibly retrieved from database derived from multiple sources. Modern mapping products range from hardcopy paper maps, digital elevation models (DEMs) to digital ortho image (DOIs) and mosaics, digital surface models (DSMs), three-dimensional (3D) city models, perspective view, fly-through, etc. While traditional mapping technologies can hardly meet all the ever increasing demands towards more, quick-turnaround, cheaper and new mapping products; new mapping technologies are emerging on the horizon. Among them, synthetic aperture radar (SAR), both airborne and space-borne, airborne integrated mapping system (AIMS), high-resolution satellite, light detection and ranging (LIDAR) are developed and employed to generate these products. Standards associated with older frame based photo technologies and paper map products are being challenged by digital technologies and new digital products. Many mapping companies are compelled to operate new and older technologies simultaneously to maintain the current production capacities, and to accommodate the changing mapping world at the same time. It is the objective of this paper to illustrate that the implementation and integration new digital photogrammetric technologies into current production line can lead to more flexible map products, reduced cost and turnaround time due to versatile data sources and process automation. The question of transition from analog, analytical to digital softcopy photogrammetry (DSP) posed in front of us is clearly not *yes or no?*, but *when and how?* instead. However, many practical problems must dealt with during the transition from analog/analytical to digital photogrammetric world.

2 BACKGROUND

Intermap Technologies is one of a long succession of companies that can trace its roots back to the early days of mapping. The recent evolution towards a digital production has been going on for the last ten years. However, DSP technologies have not completely replaced analog and analytical photogrammetric (AP) technologies due to many practical reasons. The older analog and analytical technologies are still very important and have not gone away as fast as they were originally envisioned. They are paid for and still perform some functions very efficiently. Digital technologies have created new products and processes and have served to expand rather that replace existing production capability.

Our upgrade strategy was (and still is) to introduce new technology and run both old and new production lines simultaneously for a reasonably short period of time. This provides the ability to maintain productivity, gain confidence and gradually transition to the new processes. Since 1996, LH Systems DSP workstations have been the core of Intermap s softcopy production for digital aerial triangulation, DEM extraction and DOI generation. AP equipment is still in production for planimetric and topographic mapping purposes making full use of existing investment and experienced staff.

Our current mapping production runs in a mixed analog, analytical, and digital environment. The production line is complex and has the capabilities of traditional and digital photogrammetric mapping, providing various spatial data products. The image data sources are from traditional photo, electro-optical sensors, satellite sensors, as well as 100% digital synthetic aperture radar (SAR) data collected by the company-owned Star-3*i* system (Figure 1). The 100% digital products are very flexible (e.g. Figure 2, 3, 4 and 5) and can meet the varying requirements of different users.

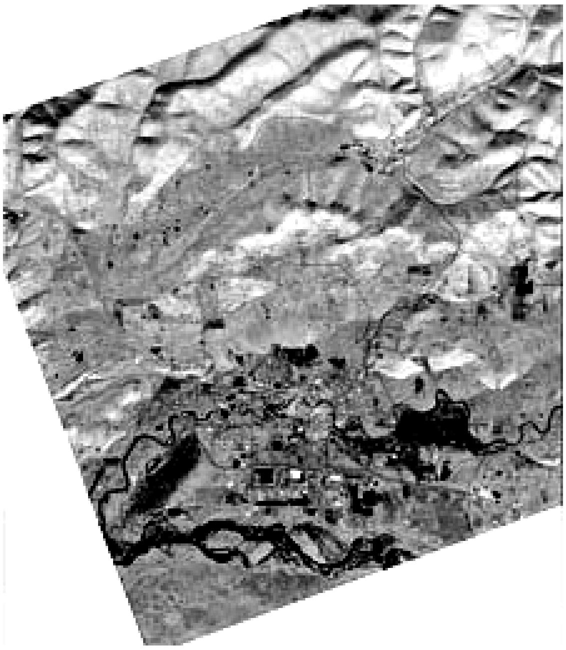

Figure 1. Star-3*i* Raw Radar Image

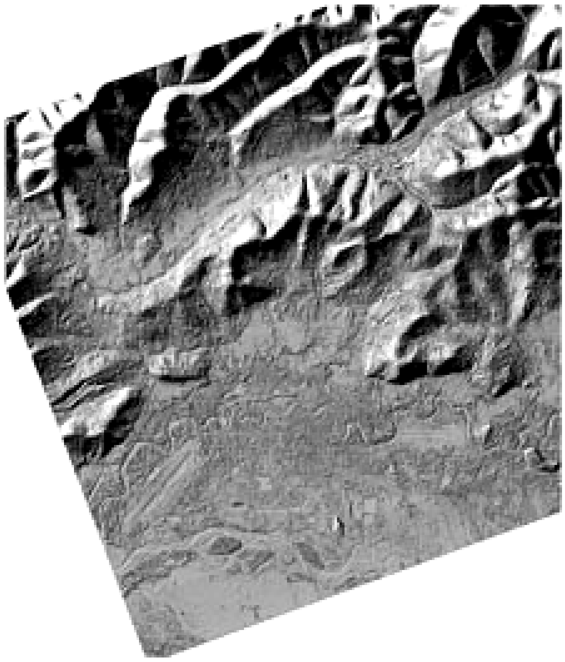

Figure 2. Shaded Relief Image

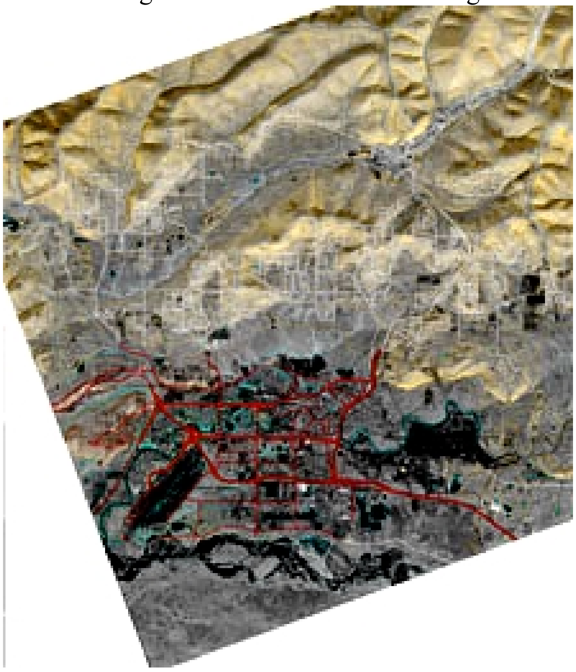

Figure 3. Ortho Image with Vector Overlay

Figure 4. Vector Map

Figure 5. A Promotional Blended Image of Ortho and Vector Map

3 PRACTICAL ISSUES AND EXPERIENCE

The transition from AP to DSP mapping production is a complex process. DSP technologies introduce new methodologies and tools into the production workplace involving significant capital expenditure and training. The complexity of the change is significant and some aspects of the products are fundamentally different. The production management, standards, quality assurance and control must also be adapted to the changes introduced by DSP technology. Many practical issues need to be dealt with to ensure a smooth transition. This section describes issues related to operating both AP and DSP mapping production lines.

3.1 Production Line Considerations

The change to the overall production line organization with DSP is *initially* minimal. The traditional areas of specialization still exist such as, aerial triangulation, image processing, vector and DEM compilation as well as cartography. This is in part due to the knowledge of the operators as well as the cost of each software module. Workstations are typically configured with the minimal amount of software required to perform the desired functions. In effect the production line changes from a series of specialized hardware components with specialized operators to a series of specialized software components with their specialized operators.

Once DSP technology is up and running in the workplace, production line loading becomes more complex. The introduction of DSP essentially creates a second production line. New projects can be either digital or analytical or in some cases both. Deciding as to how a project is handled includes, the project size, client instructions, accuracy requirements, schedule, and existing backlog resident in the shop. Many projects that are more efficient on DSP may be run on AP to utilize all machines and all available personnel. The flexibility of DSP provides tremendous value in an environment of AP machines that only perform one or two functions. It is important to purchase enough software modules for the DSP workstations to ensure flexibility or the resulting production line will be a duplication of single function AP technology workstations. Since DSP workstations are flexible they become more valuable in a mixed AP/DSP production environment.

3.2 Instrument/Platform

When operating DSP the operator has the flexibility of body movement to view the keyboard, the monitor, and superimposition of vectors over imagery simultaneously, thereby reducing body fatigue. DSP can provide a larger field of view at the same magnification level. DSP also provides the operator with the flexibility to zoom in or out while digitally collecting information. This provides a better perspective view of the surrounding terrain. However, it was also generally agreed that stereo viewing on DSP is not as acute as in the AP environment even with imagery scanned at 14-microns. The resolution of the computer screen, the stereo technology and jitter while roaming through the imagery are some of the differences. Placing the cursor onto the ground with DSP is not as comfortable when directly compared to AP technology. We found that after an adjustment period the reduction in visual acuity becomes insignificant.

A more subtle observation from running both AP and DSP in the same production environment is that it is not desirable to move an operator back and forth between AP and DSP technologies. An operator will adjust the DSP workstation to achieve a comfortable visual environment, i.e. the AP visual environment they are familiar with. This results in the operator zooming far into the imagery on the DSP to get visual comfort and in effect reduce efficiency. Once the operator has adjusted to the new DSP environment and the tendency to zoom in has been identified, similar efficiencies can be achieved. A second example supporting the adjustment to the visual environment is related to the use of stereo radar imagery for compilation. Stereo radar map compilation is dramatically different from traditional stereo photo. Radar visually looks very different (see Figure 1). Operators quickly adjust to the new sensor and do not try to duplicate the visual environment of the AP technology. Extreme magnification to duplicate the AP environment was not observed.

3.3 Training

Training is crucial to a successful transition from AP to the DSP environment. Comprehensive training allows the operators adapt to the new technology and operation environment quickly and thus be productive in a short time period. The bulk of the training involves familiarization with the computer software, the user interface and the sequence of operations required to perform the work. Training of AP oriented staff to organize and use complex computer process is a major hurdle. The typical stereo data compiler has been extensively trained in stereo photo interpretation and the single function of data compilation. Photo interpretation and enhanced stereo vision are valuable skills developed over a long period of time. The data compiler typically does not have the extensive computer skills required to manage large data sets on a complex network of computers where automation and semi-automation are becoming more prevalent.

While a single DSP workstation can perform all the photogrammetric mapping operations, the concept of single operator running a project from end to end in a practical environment does not work. Our chief photogrammetrist is tasked with being aware of all the digital photogrammetric processes, and is responsible for the training of several technical supervisors who in turn have areas of specialization. The technical supervisors are in charge of training operators based on in-house training manuals before entering digital softcopy production.

3.4 Data Storage and Data Management

DSP technology requires vast amounts of disk space for all of the digital input, output and intermediate products. Thousands of files exist on the network simultaneously creating a large storage and organizational problem. The strategy adopted to date has been the ad-hoc purchase of inexpensive disk storage and distributed deployment. As the production volume increases more disks and disk controllers are purchased. This may not appear to be planning at its best but with the rapid advancement and price reduction of disk storage technology, this plan has proved to be very cost effective and very flexible.

At Intermap, each workstation, Unix or NT is equipped with 40 to 200 GB of local disk space. Most workstations have a local eight-millimeter tape drive, with some workstations using high performance DLT tape drives. Each workstation has a CD-ROM device. All the workstations are connected through a LAN where each workstation has its own 100 Mb/second segment. Processes running on Unix systems share processors and disk space. The network acts as a single computer. The NT systems are more limited and cannot share resources as effectively as Unix. Data seldom resides on the network for more than a few days. System wide backups are not performed as they are too time consuming and not of much worth. Operators are responsible to back up project related data controlling the frequency and the temporary storage. This infrastructure easily supports DSP for most operations.

3.5 Support Costs

AP technology requires periodic calibration and mechanical maintenance. This is usually performed on a yearly basis to ensure accuracy and prolong life of the equipment. Software maintenance is also required but to a lesser degree than on DSP. DSP technology does not require calibration but software maintenance and hardware maintenance can be a significant part of the operating cost. Initial observations would indicate DSP technologies are more expensive to run primarily due to software maintenance costs and the rapid changes associated with computing technology platforms.

4 FUNCTIONAL ISSUES AND OBSERVATIONS

4.1 Image Orientation

Traditionally, image orientation has been implemented through a photogrammetric AT process that uses a number of photo identifiable ground points. While this methodology will be continued for the foreseeable future, digital softcopy AT is becoming more common. At the same time direct geo-referencing (DG), a process that establishes the on-flight measurements for the exterior orientation (EO) of each image is attracting much attention and challenging the AT methodology. Direct measurement of EO by GPS and INS is also becoming more common.

Difficulties arise in production when downstream equipment does not support digital AT or DG. The accuracy and reliability of DG might not always meet the project requirements, especially for large-scale mapping. At the present time traditional AT and softcopy AT is still more prevalent than DG. However, it can be assumed, that the combination of digital AT and DG will increase as the processes become more reliable and quality control can be implemented (Kersten, 1999a).

4.2 Analytical AT and Digital AT

Analytical AT has been performed for over eleven years at Intermap using Zeiss P1 and P3 analytical plotters as well as other supporting software and hardware. Analytical AT is a control densification process of determining 3D ground coordinates of a regular pattern of unknown pass and tie points. The pass and tie points are then used to setup stereo models on AP stereo plotters or DSP equipment. These are mature, well established ISO 9001 production processes with fully integrated quality control.

Digital AT has attracted much attention since early nineties. It has been in production for three years at Intermap when the LH Systems HATS module was purchased. In 1999, ORIMA (Orientation Management) software was added to ensure quality control and simplify trouble shooting. Digital AT has been successfully conducted at Intermap for different photo scales with different types of terrain. Results from tests and practical experience indicate that the accuracy of digital AT is at least at the same level or better when compared to conventional analytical AT

GPS determined camera station coordinates are becoming more prevalent in AT production. When appropriately applied, the use of GPS can meet the mapping accuracy requirements, and introduce substantial cost savings. However, many items, have to be carefully considered for a successful GPS assisted AT project. These include GPS observation quality, ground control requirement, and weighting relationship among different type observations, etc.

4.3 Digital AT Performance

While the accuracy is comparable with that of analytical AT, elapse time of digital AT is largely dependent on the image block configuration and on the terrain conditions. Block setup time differs with the complexity of photo block configuration and the availability of auxiliary data. Terrain type and image scale also affect the accuracy that can be achieved and the execution time required. More user intervention is needed for difficult terrain types and large-scale imagery. Ten minutes (operator time) or better per image has been reported by some authors (DeVenecia, et. al., 1996; Kersten, 1999a) for digital automatic AT (AAT) projects. Twenty to thirty minutes per image can be considered as average time from the authors experience.

It is possible under extremely difficult conditions (large height difference, different flying seasons, and heavily vegetated terrain), digital AAT will take more time than analytical AT or simply will not work at all. In these cases traditional analytical AT may be the only methodology and will still be competitive to digital AT in difficult terrain. With more improvement and more experience digital AT productivity will be enhanced. It is predicted (Kersten, 1999b) that a triangulation rate of better than 5 minutes per image can be achieved in the future. These efficiencies can also be achieved if precise direct measurements of the EO elements with GPS/INS are available. This leads to a better performance of the automatic point transfer and mensuration due to the better approximation of the block configuration.

4.4 DEM Extraction

DEM products can be derived from photographic and satellite imagery as well as airborne sensors including interferometric SAR (see Figure 3). Stereo compilation, auto-correlation and interferometric techniques are employed in the production of DEM products. If a DEM is to be used for precise engineering calculations, the accuracy is usually higher than if the DEM is to be used for ortho image generation. As a general trend, auto-correlation is becoming more and more employed for extracting DEMs.

To improve the performance of auto-correlation, it is advantageous to collect major breaklines and delineate water bodies before the auto-correlation. However, difficult terrain conditions and poor image quality makes it very difficult if not impossible to automatically generate DEM by auto-correlation. The time spent on post-editing and quality assurance will negate the time saved by auto-correlation. An alternative is to use semi-automatic methods where the softcopy system drives the cursor to pre-set locations for measurement.

DEM quality is highly variable and very project specific. Vertical accuracy requirements and the terrain type determine the DEM mass point and break line spacing. Generally, the DEM grid spacing should be such that the vertical accuracy would correspond to about $1/20^{th}$ (smooth terrain) to $1/10^{th}$ (rough terrain) of liner grid size (Ackermann, 1996). Collection of additional topographic information, such as breaklines allows for larger grid spacing. However, our experience indicates it is more productive to use a denser grid, in a softcopy environment to more accurately depict the terrain. This is made possible with the efficiencies of auto-correlation. Thus, the accuracy and reliability of the auto-correlated DEM may be enhanced due to the reduced interpolation errors and the larger redundancy.

4.5 Digital Ortho Image (DOI) and Mosaicking

DOIs combine the strengths of aerial photographs with the accuracy of vector-based mapping. Compared with their traditional analog counterparts, DOI products are extremely flexible and one of the most valuable products produced from DSP technology.

Standards. Although DOI production is widespread through the mapping industry there are no well-accepted standards. The industry has relied on the only specifications available, U.S. National Map Accuracy Standards. These standards fully support the geometric aspects of DOIs but lack in other areas. Whereas the geometric part of ortho photo production is well defined, radiometrics still pose problems, especially when dealing with color imagery (Weidner, 1999). The end product quality relies on high quality scanning, particularly for color imagery and color negative. Color quality is often highest from scanning negatives as sharpness is retained and accuracy is retained (Miller, 1999).

Ensuring the cosmetic appearance of DOI products is a significant processing step even though the product is well within accepted mapping specifications. The amount of building lean acceptable in a final urban DOI product is very subjective. With too much building lean, sidewalks and other features become obscured, building rooftops may even touch from adjacent photos. With too little building lean the product is unattractive consisting of rectangular rooftops and parking lots with no sense of urban landscape. Smearing of image pixels over sharp discontinuities in the underlying DEM or missing image pixels hidden behind objects are other problems where there are no standards.

Mosaicking and Radiometric Balancing. The quality of final mosaics is dependent upon the image orientation accuracy, fitness of photogrammetric model to the real world, radiometric quality of digital imagery and resampling methods. At Intermap, we found it necessary to develop software to mosaic and balance imagery of all types, ensuring uniform mosaic products with virtually undetectable seams. Both in-house software and commercial off-the-shelf software are used in the current production process.

The output product can be quite variable with some clients wanting a perfect image and others only wanting DOI coverage. Location of seam lines may be important to some customers and not important to others. Radiometric balancing can be very problematic if a significant number of empty bins are created during the balancing process. If too many empty bins are created the image mosaic may look nice but the data content is insufficient to support further enlargement or enhancement. Customer requirements will determine the final product specification and related processes.

4.6 Topographic and Planimetric Mapping

DSP technologies do not offer any significant performance advantages for feature collection at the present time. Automatic or semi-automatic feature extraction is still in the research domain. Feature collection is still an interactive manual process performed on both the AP and DSP instruments. However, superimposition of vector data onto stereo view screen in a heads-up environment is a significant advantage for map updating/revision and quality control. Each mapping project has very specific requirements that are easily discussed and examined in a heads-up environment. It is much easier to train operators and to ensure project standards are met in a DSP environment.

4.7 Automation in Production

The success of a modern photogrammetric mapping company largely depends on the automation of many labor-intensive processes. Orthoimage generation and mosaicking are the most advanced automated processes. Tie point selection, transfer and mensuration are the main contributing factors in automatic softcopy AT. Automation success for DEM extraction is limited and highly dependent on the nature of the project. Feature extraction or vector data collection is just in its infancy.

To date much effort was made to automate tedious labor-intensive processes in order to improve productivity and reduce human error. Currently the following processes are automated through batch processing in our production shop.

- Image importing and minification
- Interior orientation
- Block set up if airborne GPS information is available
- Automatic point measurement
- DEM extraction
- Ortho rectification and mosaicking.

5 QUALITY CONTROL (QC) OF MAP PRODUCTS

Quality control of digital photogrammetric mapping products is at best problematic. On one hand, there is no well-accepted quality standard, on the other hand, the quality must be assured for each step of the process to guarantee the final product quality. Intermap, has established strict quality control standards which are fully integrated into every step of the production process. A series of ISO 9001 documented processes has been constructed and used to control production quality since introduction of the new DSP technologies.

5.1 Hardcopy/Softcopy Imagery

Quality of the original aerial photographs, diapositives and scanned imagery is critical to the success of any photogrammetric mapping project. Quality control at this stage involves checking:

- Exposure, development, density range, forward overlap and sidelap of negatives/diapositives
- Scanning resolution, tone/color balance, artifacts (scratches, dust and dirty) of the scanned imagery within the image strip/block.

5.2 Ground Control/AGPS/AT/DG

Before AT is complete, quality of GCPs and/or AGPS can only be determined by initially checking the statistics of the geodetic adjustment and post-processing if available. The true quality can only be assessed after the block adjustment of the AT. Errors or anomalies in the GCPs/AGPS can be detected and fixed in the AT process. If DG data has been provided directly by the client, apart from a few statistics, the quality of these data can not be further assessed until ground truth is processed.

5.3 DEM and DOI

DEM quality is checked by comparing DEM interpolated heights with AT generated heights on pugged points if available, by overlaying the DEM grid/TIN onto the stereo models and then visually checking and editing the DEM data points as well as by a visual check using a gray scale shaded relief hardcopy image plot.

The quality of DOI must be controlled both geometrically and radiometrically. Geometric accuracy of is assessed and assured by comparing the rectified positions with the true positions of image identifiable GCPs and pugged points if available. For DOI mosaics, edge displacements between adjacent DOIs are verified to be less than one pixel independent of photo scale. Density/color differences among individual DOI must be balanced with proper software. The final DOI product is a radiometrically seamless mosaic that meets geometric accuracy requirement.

6 FUTURE PROSPECTS

The transition from AP to DSP mapping is well underway with the mapping community moving closer to the digital world. Companies will either embrace the technology or be left behind. The future will bring a fully digital softcopy photogrammetric mapping environment. AP technology will gradually disappear from the production lines with the continuous improvements through research and development efforts of the DSP vendors. High production efficiency can be achieved through a combination of a large degree of automation of mapping processes, system integration and comprehensive self-diagnosis and quality control.

As software and hardware become less expensive the ability to deploy employees in their homes will become possible. Internet speed will increase to the point that the transfer of large files will not be expensive or time consuming. The availability of trained staff will be a problem in the foreseeable future. Training is more efficient using softcopy heads-up systems, and perhaps in time interactively over the Internet.

7 CONCLUSIONS

Introduction and implementation of softcopy photogrammetric technologies into mapping world provide both technical and production benefits, such as process automation, versatile products, quick turnaround time and reduced cost. Currently, digital softcopy technology is still in a development stage and not mature or robust enough to replace all analog/analytical counterparts completely. A mixed analytical photogrammetric and digital softcopy photogrammetric mapping environment will continue to be used for the foreseeable future. Analytical photogrammetry is still a significant production technology required by specific market sectors such as large scale engineering applications. However, the use of analog stereo plotters is steadily being reduced in many mapping companies. For the present time operating both analytical and digital softcopy photogrammetric production lines is required.
Both analytical and digital softcopy photogrammetric technologies are required to address the current mapping market. Digital softcopy photogrammetric technologies have created new products and have served to expand rather than replace the traditional analytical production line. The new production line is increasingly complex.

Running both analytical and digital softcopy photogrammetry is a necessary bridge to a full digital mapping environment. Proper consideration of related issues will assure a smooth transition while maintaining the current production capacity. Digital end-to-end softcopy photogrammetric technology will eventually become the mainstay mapping technologies in the future, provided the digital technologies are proven to be robust enough to replace all the tasks conducted by conventional analytical methods.

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