AUTOMATION IN DIGITAL PHOTOGRAMMETRIC SYSTEMS

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KEY WORDS: Scanner, Correlation, Expert System, Edge, Image Understanding, Automated Feature Extraction, Digital Photogrammetry, Radiometric Mosaicking

ABSTRACT

The promise of digital photogrammetric systems is often couched in terms of the potential or expectation of automation. Nevertheless, increases in usable automation have been slow to develop. Still, there is a continuing increase in practical automation in commercial digital photogrammetric systems. This paper reviews the current automation in the Leica-Helava digital photogrammetric systems and our continuing investment to achieve the highest levels of practical automation for the near term. Automation at various levels is discussed in virtually all phases of digital photogrammetry. The functions discussed include scanning, GPS triangulation, automated point measurement, automated elevation measurement, automated vector extraction, automatic mosaicking and dodging, and several semi-automated operations. Real gains in productivity are evident. These developments constitute a considerable presence of practical and increasingly robust automation in digital photogrammetry.

1.0 OVERVIEW

The potential of digital photogrammetric systems has often been stated in terms which include tantalising references to the potential or expectation of automation. Nevertheless, increases in automation have been slow to develop to fulfil the promise (Leberl, 1991; Dowman, 1996). There is a continuing increase in practical automation occurring, however, in commercial digital photogrammetric systems. Leica-Helava and other researchers and vendors are exploring and implementing practical automation at all levels of the photogrammetric data collection process. We present here the current status of Leica-Helava automation and discuss its impact on productivity. The major areas of the photogrammetric process are all covered, including scanning, triangulation, elevation and vector extraction, orthophoto and mosaic production, and other related products. Worthwhile improvements in productivity are a key area of our developments. These developments include simple things such as reducing production steps as well as very complex autonomous operations.

2.0 IMAGE SCANNING

In digital photogrammetry today, the majority of digital imagery is derived from the scanning of film. Until higher resolution satellites and/or more efficient aerial digital cameras become available, film is expected to remain the major source of digital imagery. The push for higher productivity has driven us to develop techniques and mechanics for autonomous and efficient film scanning. In this area, algorithms for the automatic detection of hot spots and vignetting have been developed to dodge or balance images automatically. These algorithms are also used to assist the user in the automatic setting of tonal transfer curves to obtain a better digital image.

2.1 Automation in Image Scanning

Automation in image processing is particularly necessary as we begin to offer the DSW300 roll film scanner. This third generation scanner offers automatic interior orientation, automatic image balancing and automatic frame advance. These features combined with very high speed scanning (less than 4 minutes for 12.5 µm, 230 mm square, black and white images) have increased considerably the productivity of feeding the digital photogrammetric pipeline. Thus digital data is increasing in quality and availability at lower cost.

2.2 Advances in Networking and Peripherals

It is critical, of course, that the benefits of this rapid scanning are not squandered by bottlenecks in forwarding the data to the next stage in the flowline. Thanks to major advances in electronics and computer technology, digital photogrammetry is becoming much more productive than it was just a few years ago. The integration of higher speed networks and disk RAID systems have aided the practicality of high speed scanning and drastically reduced the need for user interaction. A single scanner connected to a large disk system is able to scan autonomously for many hours. The advent of higher speed and density peripherals has also helped to make this practical. For example, the Digital Linear Tape devices are now capable of 20 GB of storage and can be written at speeds of up to 3 MB per second. This permits a single tape to hold 200 230 mm square images when scanned at 25 µm or approximately 200 images scanned at 12.5 µm when compression is used. When one compares the size of this tape to a roll film canister, it is very impressive. The advantage that digital photogrammetry can derive from this efficient stream of data is growing continuously. One example of a very efficient production system is at the National Land Survey of Sweden (Johansson *et al.*, 1995). Here, disk RAID systems and FDDI high speed networks permit the efficient manipulation of large quantities of imagery.

3.0 IMAGE TRIANGULATION

The rapid availability of large blocks of digital imagery has given rise to one of the most successful areas of automation in digital photogrammetry - aerial triangulation. Several vendors and researchers are making good progress in this area (Fritsch, 1995). In the spring of 1995, Leica-Helava introduced the Helava Automated Triangulation System (HATS). This is an optional module in SOCET SET® (Softcopy Exploitation Tools), the standard software suite on the Leica-Helava Digital Photogrammetric Workstations. HATS uses area based matching to transfer tie and control points from image to image in the block, leaving the user only to measure ground control points (in at least one image) and help the system in the case of failed points. HATS continues to advance and is proving to be very productive. It is discussed in detail and with several practical examples by DeVenecia *et al.* (1996) and Miller and Walker (1996). Typical block triangulation rates are currently in the neighborhood of 10 minutes per image. This includes the time for measuring tie and control points, blunder detection and remeasurement, and simultaneous block solution. Not only is the productivity impressive, since the above timing must be compared with the sum of the times for the analogous operational phases of analytical triangulation using point marking devices and comparators or analytical plotters, but the accuracy is excellent also as shown in Table 1 below, which lists the root mean square errors (rmse) for the ground check points for some test areas which have been triangulated with HATS. The GSD represents the ground sample distance of one pixel.

Test Area	rms X	rms Y	rms Z	GSD
Forssa 28 images	0.054m	0.057m	0.094m	0.12 m
WiscDOT 60 images	0.085ft	0.089 ft	0.240 ft	0.15ft

Table 1. Results from HATS

Typical internal image RMS errors are 0.3 of a pixel. Table 1 reflects the error at check points which may be inflated due to additional point marking or identification errors. The following paragraphs summarize the current state of image triangulation automation.

3.1 GPS and Aerial Triangulation

In HATS, automation can start with GPS inputs. Several of today's sensor/camera systems offer GPS ready cameras including the Leica RC30 with ASCOT, which provides flight planning, navigation and pinpoint photography. ASCOT provides in-flight GPS coordinates, but Leica also provide SKI software for post-processing. The resulting GPS file of camera positions can be associated with the scanned images. This immediately "sets up" the image block for automated or semi-automated measurement of control and tie points. This lessens the number of inputs the user must perform and of course reduces mistakes. GPS can reduce the number of control points required by the block to attain a given level of accuracy. GPS is also generally more accurate than estimates provided by the user and this gives rise to faster automatic measurement as well as more reliable measurement. The success rate of automatic tie point matching as well as driving the user to control points is enhanced. This leads to substantial productivity gains as well as greater accuracy and reliability. It is somewhat mundane automation but it is very useful and impressive to be able to drive to any control point in any image of a 400 image block in less than one second.

3.2 Point Measurement

Perhaps the largest gain in productivity for triangulation is through automatic point measurement. As part of HATS, the user can choose to execute the automatic point measurement process. This process will measure tie points throughout a block of images and it will transfer measured control points to other overlapping images. This process can be executed on aerial images as well as satellite images such as SPOT and JERS. Typical measurement time for this process is in the range of 1 to 2 minutes per image. This compares very favorably against manual methods. This is particularly true when point marking is considered. Of coarse, in a digital environment, point marking is not desirable. The automatic point measurement of HATS can also exploit a given DTM to better estimate the Z value in rugged terrain. This permits even higher success rates for automatic measuement. One of the most startling reasons for this process being so successful is the reduction in fatigue for the user. The majority of the points **do not** need to be meticulously measured by the human. Instead, the user can be working on other necessary endeavors while the autonomous process measures the points for the entire block of images.

This process is typically followed by a semi-automatic process that drives the user to each missing point measurement. The software automatically positions the images near the desired point location and automatically "rectifies" the images for stereo viewing along epipolar lines regardless of the flight or scan direction of the images and overlapping strips. This automatic rectification will also scale the images to each other so that measuring tie points in images of differing scales is straightforward. This is particularly useful and necessary when dealing with satellite image blocks or aerial blocks with cross strips. It is also very useful when connecting images that wander along transportation corridors. During interactive measurement, the user merely positions the cursor near the desired point and the automatic measurement button can be used to match corresponding points. Thus even the failed points can be measured without much fatigue and at faster rates than a fully manual measurement.

3.3 Blunder Detection

Although blunder detection phases for triangulation have been around for quite some time, today's digital photogrammetry provides for several time reducing steps. Blunder detection in HATS performs image to image relative orientation, model to model connections, strip to strip connections, absolute orientation to ground and simultaneous block adjustments. At each of the above steps, blunders may be identified and the system will automatically take the user to the desired images and to the desired points. The system then presents the user with the appropriate options. Thus in only seconds a blunder can be remedied on multiple images or a point can be replaced. There is no burden of reloading images or redoing interior orientation. Again, the images are "rectified" to aid in the remeasurement process. An interesting point that is being brought out in the literature is that digital triangulation may be more accurate in practice than conventional triangulation. This may be primarily attributed to the ease with which the user can correct very tiny blunders. In analytical triangulation on analytical plotters or comparators, the time to reset stereo models and fix tiny blunders is considerable. Thus small blunders would be allowed to stay in the bundle adjustment as long as the overall accuracy of a project was being met. With digital photogrammetry and the judicious use of disk systems, small blunders can be readily fixed with a few "button clicks" within very large image blocks.

3.4 Further Automation is Currently in Testing

An even more automated method for block triangulation is starting to be used which calls for the automatic elimination of blunders and no remeasurement is generally necessary. This is because the automatic measurement process has measured many more points in the block than are necessary. This high redundancy permits more reliable blunder elimination using automatic methods. Thus, blunders can be eliminated and sufficient points are still remaining so as to yield a high quality triangulation result. This method can improve the timeline even further since the semi-automatic remeasurement is not necessary or is substantially reduced. More will be written on this technique in the near future. It has already been tried out successfully by customers. Today, substantial automation has been obtained in digital triangulation and much more can and will be done.

3.5 Usage of orientation parameters

Although it is an intrinsic part of digital photogrammetry, one often forgets the importance of the property that, once triangulation has been completed, all models are available for immediate use on any workstation in the network. No further interior, relative or absolute orientation work is required. We have also added a Model Manager, in which pairs of images are predefined as models; thereafter the operator can switch between models with a delay of only about one second - much faster that on analytical plotters with big stage plates like the BC1S and DSR15-18, and with more than two models too.

Software has also been written for exchange of orientation data between SOCET SET and various other workstations, for example many Leica analytical stereoplotters and the DVP.

4.0 GENERATION OF DIGITAL TERRAIN MODELS

4.1 Automatic Elevation Extraction

Automatic elevation extraction using area and/or feature based methods have been around for some time and continue to improve. Much has been published about these methods, for example by Helava (1988) and Miller and DeVenecia (1992), and many users are using them daily to produce elevation products such as contours and digital terrain models (DTMs). These methods have brought huge improvements in productivity for specific photogrammetric projects. In particular, small scale and/or open terrain conditions are very well suited to automatic elevation measurement. In many of these cases, automation is two to ten times faster than conventional contouring or profiling (Miller, Walker and Walsh, 1995).

Confidence in these automated approaches has grown to the extent that they have been applied in change detection studies. Customers have generated DTMs from photography acquired at different epochs in order to pinpoint urban change in Japan or forest change in Oregon and New Zealand. The objective of the latter is to quantify both cleared areas and growth; with properly chosen post spacing and computational strategies, change in the forest canopy can be estimated accurately enough to compute timber volume (Carson, Miller and Walker, 1996).

4.2 Adaptive Automatic Elevation Extraction

Leica-Helava continue to invest in this automatic process and many small practical improvements have been made. These include semi-automatic editing tools such as the automated removal of trees and buildings from a DTM when the bare ground is desired. Batch editing facilities have been added whereby previously acquired planimetric data such as ditches or stone walls in rural areas can be used to eliminate errors in the DTM caused by these features. Currently, we are testing an expert system based approach to automatic elevation production. This approach, which we are currently calling Adaptive Automatic Terrain Extraction (AATE), brings several practical benefits to the production flow. These include:

1. One step processing with multiple images: A single job or map sheet can be generated in one batch process. Multiple images can be selected covering the job in a more or less random configuration. An expert system is used to decide which images should be used and how to proceed to produce the best data. Image reshaping and image pyramid creation are performed as necessary.
2. Expert system driven adaptability: An expert system uses only a few inputs from the user and many automatically derived inputs to measure the surface. This makes the process much more adaptive to changing image and terrain characteristics. Thus, the output is more accurate and more successful.
3. Ease of use: Due to the adaptability of the expert system, the user no longer needs to prespecify large numbers of inputs such as multiple regions and strategies. Large areas can be covered in one step without pre-rectification and without post processing to merge the resulting files.

These improvements allow the computer to work harder while the user can concentrate on those areas where human intuition is required. The improvements will also minimizes disk usage. The result is a more streamlined production flow and higher quality data for less cost.

5.0 ORTHOPHOTOS AND MOSAICKING

A significant use of current digital photogrammetric systems is for the production of orthogonally corrected images or image maps. Although this process is theoretically straightforward, provided a DTM is available, customers have had a difficult time producing products that are of top quality in a minimum amount of time and steps. Some of the typical problems that often must be addressed are:

1. The images to be mosaicked have "hot spots" that are often caused by the sun angle to camera/sensor relationship.
2. The images are of poor quality and/or they are very different from one another for mosaicking.
3. Systematic effects such as hot spots and vignetting make simple mosaicking unsatisfactory.
4. Multiple processing steps such as orthophoto generation and then mosaicking result in multiple resampling and too much user interaction.
5. Multiple steps result in large disk usage, low productivity, and are unfriendly.

5.1 One-Step Image Maps

To improve this situation, several steps have been taken to exploit automation and simplification for the user to arrive at a more cost effective process. To this end, a one-step process for the production of the image maps is being made available. This process can start at various points in the typical production flow and continue to its completion. This process can start as early as before image triangulation. In this case the triangulation, DTM production, radiometric balancing, seamline generation, orthophoto correction, and seamline feathering are performed in a single batch process.

5.2 Radiometric Processing

As mentioned previously, one of the biggest time wasters in image map generation and the cause of poor aesthetic quality is acute radiometric problems such as hot spots and vignetting. Interactively setting up differing tonal curves for each image in a mosaic can also be a big time waster. It has been typical for a user to adjust each image while viewing the other images to obtain a "visual" balance. This can be very frustrating and is seldom optimal. Automation can greatly reduce these problems. One method that is being used to fix the majority of these problems is to adaptively correct each image to a common standard. This is done by first characterizing each portion of each image in terms of its radiometry. Care must be taken in the algorithms so as not to allow "artifacts" in the digital image to reek havoc in the process. For example, lakes and the film border must not be allowed to drive the algorithms. Once each part of each input image has been characterized a common radiometric goal is automatically computed or user entered. The radiometric process in mosaicking can then alter each portion of the output image in a direction toward the goal. This is performed on single image based orthophotos as well as mosaics. The result of this processing is that the seams or differences between map sheets or orthophotos are drastically reduced. This permits a much better result and makes seamlines of very high quality.

5.3 Seaming Methods

Depending on several factors such as image scale, image content, and project requirements, it may be important to have a variety of methods for mosaicking the images together. In some cases, only the user can define the seam line because all buildings and trees must be avoided for accuracy and aesthetic reasons. To increase productivity, seam lines can be extracted as vector polygons in the original images in advance of the mosaic production. Many polygons can be extracted and edited to cover the desired "orthophoto sheets". Once these are extracted, the "sheets" can be created in batch processes without further user interaction. This includes the radiometric, and seam feathering processes.

For productivity, we would like to avoid having the user manually draw seamlines. This has been accomplished in two ways. In one method, the seams between images are determined automatically. This is accomplished by using a "cost" function that examines the overlap regions, radiometric characteristics, and other factors to derive a seam line automatically. This method attempts to avoid buildings and picks a path which is usually well hidden.

In a second method, the input images are seamed at the transition from one image to another based on the most nadir sensor view. This also permits an automatic seam line and at the same time reduces errors due to relief displacement that is not correctly modeled by the input DTM. Work is continuing, however, to introduce an editing facility to handle the situation where the user wishes to change a seamline which the automatic system has placed injudiciously, for example through a building.

6.0 VECTOR EXTRACTION

Perhaps the most studied and researched area of automation is that of extracting vector data from images. Yet, to our knowledge, in practice this is one of the least automated areas of photogrammetric work. Unfortunately, it is probably the largest time user in practical production. After many years of our own research in this area and following the work of others, we are starting to see some practical semi-automated operations reduce the production time line. Completely automated operations continue to develope very slowly.

6.1 Semi-Automation in Vector Extraction

Our main emphasis for vector extraction has been to develop semi-automated tools to be used under user direction and which operate in near-real-time. New tools for the "refinement" of points and lines that are quickly measured by the user have been a major area of development. These tools take a "quick and dirty" measurement from the user and refine it using a variety of image, geometric, and photogrammetric processes. Figure 1 illustrates the types of points or "seeds" the user places for a building. The user does not worry about being precise or about squaring, thus user fatigue is reduced and extraction speed is improved.

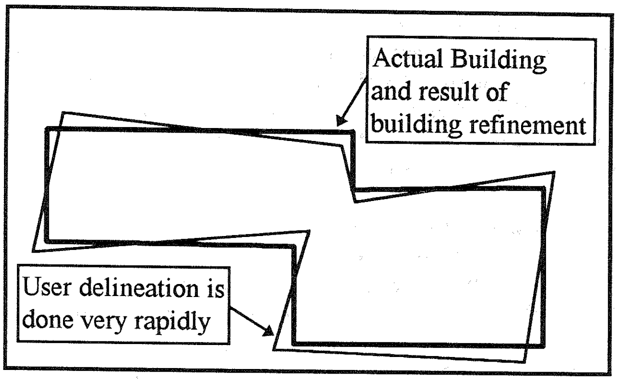

Figure 1. Building refinement

6.2 Building Extraction Tests

Figure 1 shows an example of the building refinement tool. This tool takes "seed" points from the user that are dropped within a few pixels of the actual building corners. From this quick drawing, the building is "refined" in a few seconds using edge finding, Z finding, and squaring processes. The result is consistently a precisely collected building in less than half the typical time. This was demonstrated by having a reasonably experienced stereo compiler extract building tops for many hours using conventional photogrammetric extraction and comparing this to the semi-automated method. These tests were performed using 1:11,000 scale images in very rolling terrain. The typical buildings were houses of differing sizes and orientations. Some buildings had trees around them and in some cases the trees were overhanging portions of the buildings.

The results were quite startling in that the user was able to extract more than twice as many buildings in the same amount of time. Even more startling was the user opinion of fatigue reduction. This user felt that the fatigue reduction was very substantial when compared to conventional extraction. This might be expected when one considers that the majority of the labor in vector extraction is in placing the floating mark precisely in three dimensions. The last few pixels of placement are the most time consuming and fatiguing. When using semi-automation, the user is permitted to be fast and sloppy when placing the cursor in all three dimensions. As long as the user is within the refinement algorithms search distance (such as three pixels) the speed and robustness of the tools are very good. Of course more tests are necessary to better quantify the average productivity improvement.

6.3 Automated tools in the product or in testing

These types of refinement tools are now being brought into the commercial product. Several tools are now available for linear and polygon feature collection. The following are some example refinement tools:

1. Building refinement with and without Z finding
2. Homogenous area (lakes, ponds, etc.)
3. Vegetation/Tree regions
4. Trails and centerlines
5. Road and boundary edges with and without thinning/filtering

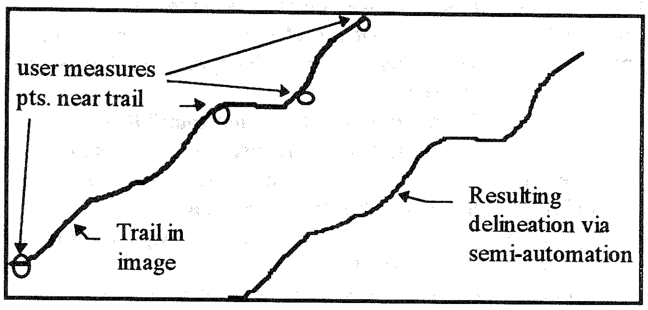

Figure 2. From a few seed points, a detailed feature can be drawn

Figure 2 shows how a detailed feature such as a trail can be extracted in detail using just a few seed points. Approximate points can be mixed with precise user defined points. The semi-automatic process will then precisely derive the feature based on image and logical processing.

In Figure 3, a man-made road edge is depicted and a small number of seed points are measured near the road edge. The image processing and logical operators will find the transition points and return a thinned and smoothed delineation.

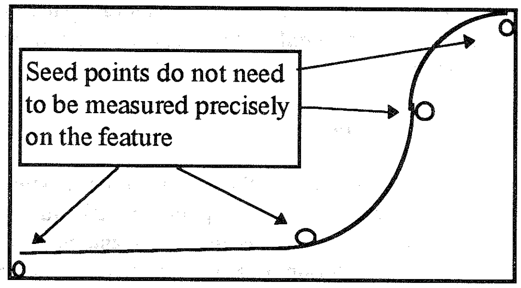

Figure 3. Road collection and refinement

6.4 Context Sensitive

One of the challenges in developing these tools is to keep the user interface streamlined. The "tweaking" of parameters and selection of different tools must be minimized or the user becomes overburdened just setting up the desired tool. One method that we are using to help in this area is the concept of a "strategy" for each tool type. The strategies allow several permutations of algorithms but they can be named in a user intuitive way. This permits easy switching from one tool type to another. In addition, the user can setup the default collection mode on a per "class" or "feature type" basis. This permits the software automatically to set the desired collection mode based on the context of the feature class or type. This eliminates the step of changing collection modes during typical extraction. For example, the default collection mode for houses and industrial buildings might be "semi-automatic", while the default collection for churches might be "manual" (assuming churches are too complex for semi-automation). Another example might be "semi-automatic center-line" for trails and "semi-automatic spline edge" for streets or highways.

Overall, this semi-automated approach is proving to be user friendly and offers genuine enhancements to productivity for vector extraction. Much work will continue in this area and timeline improvements in the range of two to four times appear to be plausible.

7.0 SUMMARY

It is an interesting time to be working in the transition to digital photogrammetry. The rapid increase in computing power and the advent of practical digital image handling permits developers to advance the productivity of photogrammetry in a fairly continuous way. When the automation is synonymous with productivity increases or ease of use, advancement has been made. Automated operations have been discussed and are continuing to permeate nearly all phases of digital photogrammetry. Most of these improvements are being put to use rapidly after their introduction. Automation is expected to remain a key area of Leica-Helava development for some time.

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