TOWARDS A HIGHER LEVEL OF AUTOMATION FOR *SoftPlotter*™

Yan Lue, Senior Photogrammetric Engineer

Vision International
A division of Autometric, Inc.
502 Earth City Expressway, Suite 203
Earth City, MO 63045, USA
lue@stl.autometric.com

Commission III, Theory and Algorithms

KEY WORDS: Photogrammetry, Automation, Matching, Interior Orientation, Feature extraction, Tie Points selection

ABSTRACT:

In this paper we present the efforts on two important aspects of automation for the digital photogrammetry system: Automatic Interior Orientation (*AIO*) and Automatic Tie Point Selection (*ATPS*). The latter one covers the traditional point selection, transfer and mensuration. Both modules are available in the SoftPlotter™ softcopy photogrammetric workstation from Vision International. A fully automatic *AIO* module based on template matching, together with *LSM* techniques suitable for most commercially available aerial cameras, has being running on many SoftPlotter™ for over a year. A success rate of one hundred percent for fiducial recognition with very high accuracy was achieved on several hundred test frames. Thousands of frames have been processed with *AIO* by SoftPlotter users with satisfactory results. The processing time averages only a few seconds per frame with eight fiducials. Another fully automatic module *ATPS* is based on a series of sophisticated image matching algorithms and strategies. The beta version has been applied to some practical projects. The *ATPS* results for a variety of strips covering image scale from 1:3400 to 45000 with all kinds of different textures, including urban area with strong distortion, forest, mountain, wetland, desert, rivers, lakes etc., are very promising. The feedback from the real world is very positive too. The averaging success rate was about 85 percent. The processing time was less than a half minute per frame with points on nine standard positions.

0. INTRODUCTION

Digital photogrammetry (*DP*) is coming out from its research and development period and into day-to-day practice. Commercial photogrammetric companies are rapidly turning to digital photogrammetric workstations and systems to meet production requirements. Traditionally, the most time-consuming and labor-intensive task is the mensuration of the all kinds of points, such as fiducial marks, ground control points, tie points. Somewhat surprisingly, however, while most commercially available digital photogrammetric systems have provided automatic photogrammetric data collection and product generation for *DEM* and orthophoto for quite a while, the most fundamental operations of photogrammetric processing like interior orientation, tie points selection and mensuration needed by aerial triangulation (*AT*) are still often performed manually as on an analogue or analytical plotter.

In this paper we present our efforts on two important aspects of automation for the digital photogrammetry system: automatic interior orientation (*AIO*) and tie point selection (*ATPS*). The first part gives a brief description on the basic concepts and technical strategies and then introduces some results on thousands of aerial photos taken by eight popular aerial cameras (*Wild RC8, RC10, RC20, RC30, Jena LMK 1000, 2000, Zeiss RMK TOP 15, RMK A 15/23, 30/23*) (Lue, 1995). The second part describes methods and strategies for *ATPS* procedure, which shares a similar philosophy and methodology but uses more sophisticated strategies and organization. A summary about the *ATPS* results on 16 data sets with different image scales, different scanning resolutions and all kinds of different textures, including urban area with strong distortion, forest, mountain, wetland, desert, rivers, lakes etc. is also provided.

Some technical and practical points is discussed in the successive section, then a conclusion is drawn in the last part of the paper.

1. FULLY OPERATIONAL AUTOMATIC INTERIOR ORIENTATION (AIO)

In photogrammetric processing image measurements of all points, no matter if they are tie, ground control, feature or terrain elevation points must be reduced to the camera system central perspective coordinates. For the *DP* processing a hardcopy film is arbitrarily put on a scanner for digitizing. A set of transformation parameters is therefore needed to derive the film coordinates from the scanning ones or vice versa. The tasks of recognizing and measuring fiducials for deriving the transformation parameters between the scanned image and camera coordinate systems comprise the two basic tasks of interior orientation. As well known, the latter one has been. well established. The automation of the interior orientation needs to concentrate primarily only on the former

Interior orientation in most existing systems require at least the first one or two fiducials to be measured manually before the remaining fiducials coordinates can be determined by various semi-automatic methods. On the contrary, *AIO* of SoftPlotter^{TM} implements interior orientation *fully* automatically without the need for any approximations or intervention by a human operator.

The approach used for *AIO* is a revised version of the *RG-DW* matching scheme, developed for *Digital Ortho Module of ERDAS 7.5* for DEM generation (Lue, 1991, 1992), augmented with the successive *LSM* to yield with very high accuracy. For simplicity, we outline the methods in the following part. The reader is encouraged to refer to the literature for the detail.

1.1 Basic Concepts And Technical Strategies

Basic tools

The basic tools used in *AIO* are: *three levels of pyramid images, template matching, spiral searching strategies, least squares matching (LSM).*

Take full use of a priori knowledge

Compared with other image matching problems, the searching for the camera fiducials is simpler, because the fiducial has a known shape and location on the digital image. This kind of *a priori* knowledge can be easily exploited to simplify searching and processing.

In general, the fiducials are normally located on the corners and/or on the edges of a film as shown in Figure 1, and different cameras have their own fiducials with different shapes. To perform the template matching for different fiducials a set of fiducial templates is needed. An easily extensible database containing templates of fiducials for different aerial cameras has been established for *AIO* through scanning of fiducials with a very fine resolution, as shown in Figure 2. Using the fine resolution allows the templates to be better resampled to match the scanned pixel size of any input image.

Clearly, it is unnecessary to work on an entire digital image to perform the fiducial template matching. As mentioned above, the *a priori* knowledge about the fiducials positions allows for a quicker searching of a patch of pixels only surrounding the predicted fiducial location, eliminating the need to generate pyramid images for the entire frame of original image for *AIO* use.

Template matchig on three pyramids and LSM work together

It is essential to achieve a good approximation prior to *LSM*. The template matching is less sensitive to poor initial approximations than is *LSM,* while *LSM* typically provides better final results than template matching. Therefore more attention was provided to developing strategies to assure reliable template matching to provide better initial value to guarantee the desired *LSM* results.

For the first fiducial, a small patch, say 512 by 512 pixels, is read from the original digital image. In order to get a higher efficiency for fiducial searching with less effort, three levels of pyramid images (Figure 3) and the original image for each small patch are used throughout the template matching processing, e.g. in case of 25 microns of scanning resolution for an original image the resolution for its three pyramid images will be 100, 400 and 1600 microns respectively. More effort and a relatively wider search range for the first fiducial are normally required due to the limited information to predict its position.

The matching starts at the lowest pyramid resolution level, and the solution obtained is then used as a starting point for the next level's matching. A set of dynamic correlation coefficient thresholds and dynamic window sizes for the template matching are adopted. In general, a lower threshold for a higher level and vice versa to avoid a possible wrong recognition for a lower level or lost matching for a higher level to ensure a higher success rate of recognition. A spiral searching strategy (Lue, 1991, 1992) is used to locate each consecutively smaller patch and different searching ranges during the spiral searching process are accordingly used within each pyramid level.

Successful location and mensuration of the first fiducial allows for the computation of a translation bias so that a smaller search range can be used for the second fiducial to gradualy reduce the effort. Its location can be roughly predicted using the computed translation bias. A satisfactory result can therefore be reached using a smaller patch size, say 256 by 256, vice 512 by 512, when searching for it. The fiducial diagonally opposite to the first one is always treated as the second one for geometry consideration for later use.

Once the first two fiducials are located successfully, initial transformation, scale and rotation parameters between the scanned and camera systems can be roughly calculated. This transformation is used to predict the locations of all other fiducials. As a result, the remainder of the fiducials can be located with an even smaller search patch size, say 128 by 128, as the *AIO* proceeds. Once all fiducials are well located the final transformation parameters are calculated again and saved for subsequent use.

Some practical aspects

If the scanned fiducials are located too close to or too far away from the border of the scanned images, which sometimes happens, the search for the initial fiducial may fail. To survive such situations the algorithm sequentially attempts to locate other fiducials as the first one. If it fails again a larger patch size will be used in searching for the first fiducial. Then the whole processing is repeated.

Sometimes one or two fiducials might be missing or obscured. This should not significantly affect the final results, because the remaining fiducials which span the image provide more than adequate observations for solving the interior orientation parameters. However, at least three, or for safer, four fiducials are required to achieve good quality of the transformation results.

In the case of the flight direction is different from the scanning direction the search and measuration will yield incorrect results. The difference in fiducial ordering due to scan direction must be taken into account. The software simply provides a way to let the user identify the orientation of the imagery with respect to the flight direction by identifying a calibration edge as an input parameter if the direction is different from the default. Figure 1 presents the fiducial numbering sequence from a United States Geological Survey's (USGS) aerial mapping camera calibration report. The default calibration edge is on the left when the camera is viewed from the back.

For example, against the order of (1 2 3 4 5 6 7 8) for the calibration edge located on the left as shown in Figure 1, the order of (4 3 1 2 8 7 5 6), (2 1 4 3 6 5 8 7) and (3 4 2 1 7 8 6 5) will be automatically used for the calibration edge to the top, right and bottom respectively, as chosen by the user.

Quality control

At the end of the fiducial searching process for each frame, a set of transformation parameters is derived based on the coordinates of fiducials in two different systems. If the *R.M.S.E.* is over a certain threshold, the software will warn user of the results and also record it in the *AIO* report for later post-checking when executed in batch mode. During the processing if the correlation coefficient of the *LSM* for any fiducial is lower than the threshold, it will be automatically rejected and logged in the *AIO* report.

1.2 Results

Before the beta version of the *AIO* was offered to Vision's users in early Spring of 1995, a total of over 400 digitized b/w and color frames with different image scales, scanned by different commercial scanners with different formats and different scanning resolutions ranging from 15 to 30 microns per pixel, were tested. One hundred percent success rate of fiducial recognition with a 0.1 subpixel positioning accuracy and a *R.M.S.E* of 0.325 pixels for coordinate system transformation was achieved. The performce time varied from 5 to 9 second per frame with eight fiducials, which is largely depending on the image and scanning quality (Lue, 1995).

Recently to respond to *OEEPE's* workshop, the author ran *AIO* on a *SGI* Indigo2 with *R4400/200MHz* workstation for the *OEEPE FORSSA* data set of 28 frames taken by camera *Wild RC 20* and scanned by *Zeiss PS1* scanner with scanning resolution of 30 microns per pixel. The *AIO* running time for all 28 frames was 4'46'', i. e. less than ten seconds per frame with eight fiducials. The correlation coefficients for all 224 fiducials are over 0.9 and the *R.M.S.E* for the transformation was 0.17 pixels or 5.21 microns.

As further proof, *Vision* customers have reported satisfactory results with *AIO* on thousands of different digital frames.

2. FULLY OPERATIONAL AUTOMATIC TIE POINT SELECTION (ATPS)

The topic of automatic aerial triangulation (*AAT*) has been discussed a lot recently. It is well known that the aerial triangulation consists of two major phases: mensuration and calculation. The latter one has been successfully solved in 1970's and achieved its very high accuracy to meet all kinds of application for several decades. The focus of *AAT* for *DP* has naturally fallen onto the former one, which corresponds to the tie point selection, transfer and mensuration of the image coordinates. That was the motivation to develop *AIO* first and then *ATPS*, since much of *AIO* is a prerequisite of *AAT*. If and only if we have *AIO* and *ATPS* together with *AT* we could say we have been reaching the *AAT*.

On the other hand, there are many factors which determine the final accuracy of the *AT*, such as flight quality including the situation of overlapping, picture taking, quality of scanning, quality of the ground control points, the capabilities of the *AT* software, as well as the configuration, accuracy, reliability and number of tie points. Actually, only the last four factors are derived directly from *ATPS* and require our attention at this stage to implement the *AAT*.

According to Vision's customers - productive photogrammetry companies - the *AT* results derived from the semi-automatic tie points selection and measuring of the SoftPlotter^{TM} met all standard requirements of conventional ones. For this reason, to verify the *ATPS* results without involvement of other factors, which might affect the final accuracy but out of control of *ATPS* software, we simply chose the visual check on the computer screen to get the statistics of success/failure instead of through the *AT* results.

A similar philosophy and strategies - like multi-level image matching with a dynamic window size, spiral searching and *LSM* etc. - are still used for *ATPS*, though feature extraction, a variable threshold for different level of pyramid images and a more sophisticated organization with strategies distinguished it from *AIO*.

2.1 Basic Concepts And Technical Strategies

Basic tools

The basic tools used in *ATPS* are: *3-4 levels of pyramid images, point-like feature extraction, multi-scale matching, spiral searching strategies, LSM.*

Four basic factors

As mentioned above, configuration, accuracy, reliability and number of tie points are only factors controled by *ATPS* which will directly affect the final *AT* results. With this consideration, the measures adopted by *ATPS* in order to meet *AT's* requirements for these four aspects are:

Configuration:	standard position (Gruber points) with six more additional patterns (Figure 4)
Accuracy:	using *LSM* at the final step to achieve high accuracy
Reliability:	using the multiple criteria control to reduce the rate of wrong matching
Number:	3 x 3 points per frame at least (see Figure 4). At each position single/cluster point is possible.

3-4 pyramid image:

Similar as *AIO*, one of the most important strategies to make the *ATPS* feasible is the use of pyramid images throughout the processing. The levels of pyramids are separated by a scale factor of 4. The total levels for *ATPS* are normally about 3-4, depending on the scanning resolution (the finer resolution, the more levels).

Automatic overlapping range prediction

The *ATPS* starts from an automatic prediction of percentage of overlapping range between the immediately adjacent images from the highest pyramid image to determine where to put the selected tie points and from how many images (two/three/five - stripwise or four/nine/fifteen - blockwise) and which images to do matching to find conjugate points. The horizontal and vertical parallaxes obtained in this stage are also be used to partly guide the subsequent searching processing. The percentage of the overlap will be updated if the difference between the initial value and the value from the original resolution is over a certain threshold.

Searching starts from the highest level with help of the value of the initial bi-direction parallaxes, then a selected point always serves as the approximations of the next level. The process is subsequently repeated by the remaining levels of the pyramid images until the matching are successful on all levels including the level zero (original image), on which the *LSM* is carried out to get the final measurement.

Point-like feature extraction and a combined matching

A point-like feature extraction around the selected area of the central column of each master image (Figure 4) is executed on the next higher level of the original image, based on which the locations of the features on other levels are simply derived. The matching proceeds from the highest level to the lowest level with a spiral search within a certain range. The spiral search will be concluded automatically when certain indicators show no more hope for further improvement. Once the matching is successful for a feature on all planned levels, additional feature extraction in a small area around the feature on the original image, e. g. 5 x 5 of primary image, is carried out again to get the feature better located. The point-like interest operator used throughout the system is a simplified version of the Foerstner's (Lue, 1988)

The reason that the feature extraction is carried out on a certain higher level rather than on the original image and all levels of the pyramids is to avoid some possible noise existing on the original one and also to save effort/time of repeated feature extraction. With this approach it doesn't need to concern the feature's accuracy too much because the final *LSM* will well take care of it and give even higher accuracy than any feature extract operator does.

Optional parameters

The entire process of *ATPS* is automatic and though no approximations are needed, there are a number of optional parameters for user to choose; like which pattern (Figure 4), the size of the patch for feature extraction, the number of the features to be used, independently matching for each selected point or based on the info from the existing points. Once the parameters are defined at the beginning, the tie points will be automatically selected with a desired pattern and number.

In each defined patch, normally many more features than needed are extracted in order to avoid loss of any possible features by automatically setting a relative lower threshold for the interest value, especially for the areas with few textures and bad contrast. Therefore the number of tie points for each patch are highly flexible to be chosen accordingly through using a proper parameter. On the other hand, an ordering list of features according to their interest values is made to let the best features with higher weight value always be treated first.

It should be pointed out that some commercial photogrammetry companies do not want to have too many tie points, instead to prefer a minimum but sufficient number of tie points, especially for the normal areas and applications, even though the processing is automatically carried out. The point here is that the quality of the final *AT* results are good enough to meet the requirements, that drove us to provide different tie point configuration patterns for different users to choose. Total seven patterns for tie points distributed in a homologous image segments are provided to give the user a high degree of flexibility (Figure 4). This is also useful when some areas fall into the water or other difficult fields like forest, brushes, shadows etc. Points selected from the additional areas will compensate the lost points in other areas.

Quality control

The algorithms set up several checks on their own, such as the history of the matching for each pyramid level, *LSM's* accuracy indices etc. An affine transformation is also applied to identify the possible mismatches after enough points are selected.

It should be pointed out that no ground control points (*GCPs*) or any point approximations are needed for *ATPS*, though a set of transformation coefficients can be derived from existing *GCPs* to partly reduce the effort of tie points searching. Similarly, *GPS* data, if available, would also play an important role to make the searching more effective.

Interactive tool

Unlike *AIO*, *ATPS* can not easily reach hundred percent success rate all the time, a certain interactive involvement by the human being is often needed, especially in the areas of forest, urban area with a large image scale that normally causes a large perspective distortion. In order to compensate the loss of tie points in such areas SoftPlotter^{TM} provides users with a very convenient tool to display three (for a single strip) or six frames (for two strips) altogether on a computer monitor to let user check the quality or add/delete any points easily.

The selection of tie point with this tool is a so-called semi-automatic one. Its automatic level depends on how many points (tie points or ground control points) are already exist. Normally, it is recommended to run *ATPS* first, because many points selected by *ATPS* will be used to calculate the proper transformation parameters to issue a prediction for any desired position. For instance, to add one point that is required by an user is to select a point manually only from the master image and then click a special button ("Auto Place" or "Pug Point") that triggers a series of calculations, including roughly locating all corresponding points from the homologous images and conducting the *LSM*. Then, all conjugate points will be automatically and precisely found from the slave images and simultaneously displayed on the screen.

2.2 Results

Total of 16 data sets with 60-80 percent overlap were tested with *ATPS* so far. All data sets were b/w, with the exception of one color data set. The image scale covers 1:3400, 4000, 4300, 6000, 9600, 24000, 45000 which were scanned by different scanners with different formats and resolutions (15, 22.5, 25, 30 microns per pixel). The data sets containe all kinds of different textures, including urban area with strong distortion, forest, mountain, wetland, desert area, rivers, lakes etc.

The average success rate is about 85 percent. Some data sets even achieved hundred percent success. The average processing time was less than a half minute per frame with points on nine standard positions on *SGI Indigo2* with *R4400/200 MHz* worksattion.

Interestingly, little visible texture and bad contrast in some areas even made the manual recognition difficult, while *ATPS* found the conjugate points easily. Premarked signalized points were always successfully selected, as long as they fall into the area defined by the selected pattern. For the urban area with a large image scale and distortion, as included in the 16 data sets, the results were also very promising.

As pointed out before, unlike *AIO* which deals with fiducials of a fixed shape and a specific location on an image, *ATPS* has to deal with a natural earth surface which varies everywhere, one can not guarantee to find corresponding points all the time. But with a little help of an auxiliary semi-automatic tool in a relative difficult area, much less effort than traditionally is needed, e. g. for a strip with ten frames of urban area with scale of 1:3400, the time for adding lost tie points after running *ATPS* was only a few minuts.

3. SOME POINTS

Batch mode for AIO and ATPS

Because an entire interior orientation process is a fully automatically implementation without any necessity to display images or do any measuring on the computer screen by a human operator, and also without the need to generate pyramid images for a whole original image, it is convenient to complete it with a human unattended model to take full use of off-working hours. Besides an easy-to-use graphic interface of the *AIO*, a simple command line interface for *AIO* has been also provided to users, so that a large numbers of frames can be conveniently processed in a batch mode during off-working hours.

As expected, *ATPS* requires more storage space than *AIO* to implement its batch mode which might cause some serious space problems when work in off-working hours for a large block, at least for the time being. With the fast development of computer hardware, however, using a batch mode to deal with a huge block in off-working hours should not be any problem.

Interactive tools

Due to the very high degree of diversity of the natural earth surface the mapping world faces everyday, we can not easily spell an end to interactive work to tie points selection. Even with continual hard work to reach a very high level of automation for *ATPS*, e. g. supposing only one percent work needs involvement of human being, the need for interactive processing is still there. With this philosophy, we would never abandon the existing interactive tools, instead, we are always trying to make them more powerful, more effective and easier to use.

Customer's feedback

The success of *AIO* and *ATPS* relies not only on the research work itself, but also, more important in some respects, on the wide support and quick feedback from *Vision's* customers. For example, it would be impossible to get more than 400 frames with all kinds of different fiducial shapes and many unpredicted problems for *AIO* testing if we had restricted our work in the office of *R&D* only.

Customer support

This is indeed another side of the customer's feedback. Both sides working together would greatly propel the *DP*'s development and application to get into a prosperous period.

4. CONCLUSION

The fully automatic interior orientation technique and its operational package *AIO* has been becoming a standard tool of a *DP* system. The tie point selection, transfer and measurment conducted by a human operator is also going to be totally or near-totally replaced by fully automatic tie point selection package *ATPS*. Products derived through the digital photogrammetric processes with a higher level of automation have demonstrated their potential for satisfying customer demands. It can be generally concluded that the higher level of automation of *DP* has been reached through the use of a series of proper strategies and is proceeding to a briliant future.

Future developments will aim to raise the success rate and reliability to support a continously higher level of automation and in turn to further reduce the interactive work.

5. REFERENCES

Lue, Y. 1988, Interest Operator and Fast Implemtation, International Arch. of Photogrammetry and Remote Sensing, Vol. 27, B3, ISPRS Congress Kyoto, pp. 491-500.

Lue, Y. and K. Novak, 1991, Recursive Grid-Dynamic Window Matching for Automatic DEM Generation, Technical Papers, GIS/LIS, ACSM-ASPRS Fall Convention, Atlanta, pp A254-260.

Lue, Y. and K. Novak, 1992, RG-DW Image Matching Scheme and its Application, International Arch. of Photogrammetry and Remote Sensing, Vol. XXIX, B3, ISPRS Congress Washington, D.C., pp. 813-819.

Lue, Y. 1995, Fully Operational Automatic Interior Orientation, Proceedings of GeoInformatics'95 Hong Kong, Vol. 1, pp. 26-35.

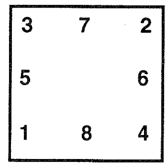

Figure 1: Fiducial distribution on an aerial photo and the numbering sequence by USGS of the USA

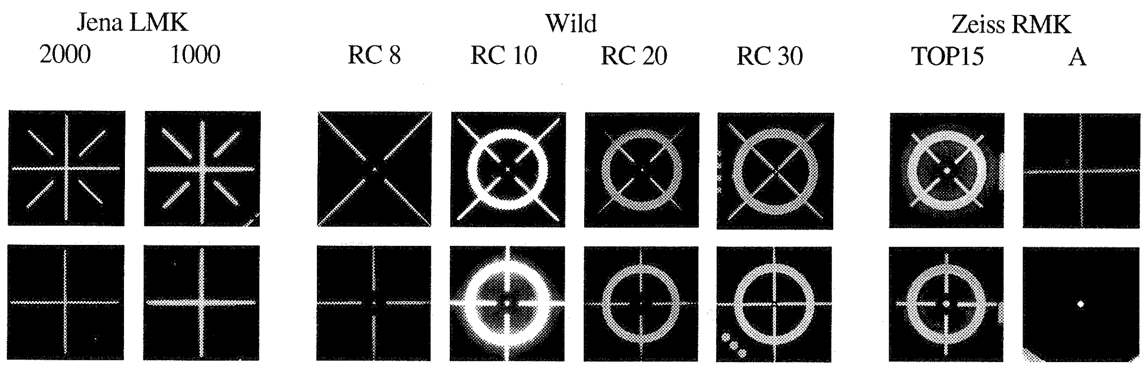

Figure 2: Aerial cameras and their fiducial marks the current AIO of SoftPlotter supports.

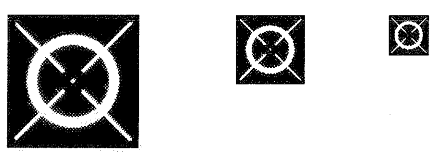

Figure 3: Several levels of pyramid images are applied to reduce the searching effort involved.

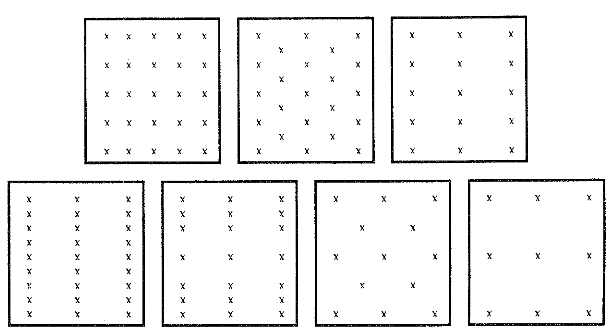

Figure 4: Seven configuration patterns of tie points the current ATPS of SoftPlotter supports.