DYNAMIC WINDOW SIZE LEAST SQUARES MATCHING FOR AERIAL TRIANGULATION POINTS

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ABSTRACT:

When only the measuring of the aerial triangulation points is concerned, there is no need to digitize the whole frame of the aerial photographs, because the triangulation points locate always at the specific so called Von Gruber positions. It is sufficient to digitize only a small area at these positions. But to automatically pin point where should be digitized in the overlapping photographs is very difficult. Therefore we developed a semi-automatic solution using the Rollei RS1 digitizer to digitize only a small area where the triangulation points are supposed to locate (the standard position).
Within each of these small areas enough triangulation points should be selected and transferred by image matching technique into the corresponding areas in neighboring photographs. The selection of the points is done automatically by interest operators. The matching of these points between different photographs is done by the Least Squares Matching (LSM) method. In order to obtain more reliable and accurate result a procedure using dynamic window size and checked by the cross correlation before and after the LSM is proposed.
In the dynamic window size matching, instead of one fixed size, several different sizes of window will be used to determine which one gives the best result and to check if the selected result is reliable. Whenever no reliable result could be obtained, the system switches automatically to manual selection of the matching windows.

1. Introduction

In the development of the automation in Photogrammetry by digital image processing, the automation of the measurement of aerial triangulation points (TPs) is a very promising one, because the measurement of the TPs does not need any sophisticated image understanding. It can be done by the low level gray value matching alone. No knowledge about the image content i.e. no recognition of the objects is needed. Therefore there has been great success in the past few years in studying the problem associated with it and in developing proper commercial systems to conduct the automatic TP measurement in the practice. The Digital Comparator Correlation System from Helava for example, was the first commercial system for fully automatic measurement of the TPs (Helava, 1987). The same system is used now in the Leica-Helava digital photogrammetric workstation DPW.

Since low level gray value matching is good enough for TP measurement, the most difficult task in the development of such fully automated system is not the matching itself but the finding of the conjugate positions in different overlapping photographs, i.e. to find the overlapping areas between the neighboring photographs within and across the strips . Without this knowledge the search work for transferring TPs into overlapping photographs would be intolerably large and the chance of false matching would also be too big. In the Leica-Helava DPW system for example, the operator has to give the information about the approximate layout of the strips, the beginning and ending of each strip, etc., so that the system can calculate the relative position of all the photographs in the block. But in mountainous areas in spite of this information, the system fails to find the correct conjugate areas very often because of the large relief displacement. In such case human operator is always needed. In the MATCH-AT system, developed by the INPHO Stuttgart based on the research result of Tsingas (Tsingas, 1992), the approximate layout of the block should also be known before the system can start the matching. In the Image Station from INTERGRAPH there is still no automatic measurement of the TPs. The points have to be measured manually like in the analytical plotters. From all these examples we can see that a blind, fully automatic measurement of the TPs without any prior knowledge of the block layout or the approximate position of each photograph is very difficult. Even in the future when every camera position could be given by the GPS navigation system, the problem of mountainous area still needs to be solved.

In the Surveying Engineering Department of the National Cheng Kung University there is a RS1 image digitizer from Rollei, which is designed to digitize each time a small patch of the photograph by its CCD camera with 512x512 pixels. Since for the measurement of TPs, it is not necessary to digitize the whole photograph and since the blind, fully automated system is not easy to develop, we decided to use this RS1 to develop a kind of semi-automatic TP measuring system. We call it the semi-automatic system, because the area which should be digitized is determined by the operator not by the computer. That is, conjugate areas in the overlapping photographs are searched by the human operator. Each time only a small area is digitized by the CCD camera. This area will be called the tie area, because in it the aerial triangulation tie points should locate. Since the conjugate tie areas in different photographs are selected and digitized by human operator, the difficult blind searching of them in the whole block or in a whole photograph is avoided.

After these areas have been digitized, TPs will be defined in them and transferred between them. The methods used in our system for defining and matching the TPs are mainly adopted from the Helava's proposal for the DCCS. The greatest change in our system is that instead of using one fixed window size, we use several different sizes for the Least Squares Matching window in order to increase the reliability and the accuracy of the matched results. Another change is that we match each time only one pair of tie areas. There will be no multiple image matching like in the DCCS.

With this semi-automatic point measuring system, we combine the point transfer and the point measurement in one procedure. Both the speed and the accuracy of the aerial triangulation point measurement are increased. Since only small tie areas are digitized, the data amount is very small. There is no problem concerning the storing and the managing of the image patches. An ordinary PC486 is used for this system.

After the tie area is digitized, image pyramids will be built up. From all the conjugate tie areas, one will be chosen as the master tie area and the rests as slave tie areas. In the highest level (with the lowest resolution) of the pyramid of the master tie area image, the Foerstner interest operator is used to find the places where the windows for defining the TPs should be. A number of such places should be chosen, in case that some would fail in the subsequent matching. These places will be traced down through the pyramid to the lowest level (with the highest resolution). The actual TPs will finally be found there.

While applying the Least Squares Matching technique, we have noted that the reliability is a problem. If the initial approximate position for starting the matching is not accurate enough, the LSM method could converge to a false place and there is no information from the matching itself to judge the reliability. Also the size of the matching window is a problem. There is no such thing as the best window size. Different window sizes converge to different positions, the difference can some times be larger than 0.2 pixel. Therefore we have developed a strategy to cope with these problems. Instead of one fixed window size, we use several different sizes for the LSM and by analyzing their normalized cross correlation coefficients (NCC) after the LSM matching, the best result is selected. When no reliable one could be found, that point will be abandoned. If there are not enough reliable points in a tie area, the system will switch automatically to the manual selection of the target and the search windows in the master and the slave tie areas respectively.

2. System Configuration

The whole system is built up on the basis of the Rollei RS1 scanner running on a COMPAQUE PC. The RS1 is designed for digitizing the photographic film with very high geometric accuracy at low costs. Which is achieved by using a reseau plate (Luhmann and Wester-Ebbinhaus 1986). The main parts of the RS1 are a CCD camera and a glass picture carrier with 2mm spacing reseau crosses all over its entire surface. The CCD camera has an array of 512x512 pixels and locates above the picture carrier. The pixel size in the film is approximately 8μmx 6μm. Therefore the total area of the film which can be digitized at one time is approximately only 4mm x 3mm. But the CCD camera can be moved to any place over the picture carrier by step motors, so that the whole picture can be digitized patch-wise. Since step motor is not very accurate, Luhmann and Wester-Ebbinhaus developed this cheap solution of using reseau plate to obtain the high precision absolute reseau coordinates for each pixel.

Two different light sources are built in the RS1 which can be switched automatically in turn. When the bottom light is switched on, the light goes through the film into the CCD, and the film can be digitized. When the side light is switched on, only the reseau crosses are imaged into the CCD. In this case, the pixel coordinates of the reseau cross center can be obtained after an automatic matching of the cross image to the standard template. Then the transformation parameters from the pixel coordinates to the reseau coordinates can be calculated. Since the absolute coordinates of the reseau crosses are known, the absolute coordinates of each pixel can be calculated by the transformation parameters.

The distance between the reseau crosses is 2mm and the CCD digitizes an area of 4mm x 3mm, so that it is guaranteed that there will always be at least 4 reseau crosses used for calculating the transformation parameters. The area encompassed by the 4 crosses has approximately 240x350 pixels. In order to reduce the error caused by extrapolation, only the pixels within the four crosses will be used for the TP measurement.

The CCD camera can be driven by the reseau coordinates or by the photo coordinates. In our case we drive the CCD camera to each tie area in the photograph with photo coordinates which are obtained from digitizing the paper print on a digitizer tablet. Each time when the CCD camera moves to a new position, it will first take the image of the reseau crosses, calculates the absolute reseau coordinates of each CCD pixel, than take the image from the film. But two serious problems are associated with this solution. First there is a long waiting time for the RS1 to switch on and off the two light sources and to calculate the absolute coordinates of each pixel. Second, due to the constant short period on and off switching of the light, the light intensity from patch to patch is uneven, which induces false gradient in the gray value along the connection border of patches.

Details about the construction of the instrument and the calculation of the absolute pixel coordinates can be found in the literature and will not be given here any more.

3. Digitizing the Tie Areas

Prior to the scanning of the tie areas, their positions and approximate coordinates in the photograph have to be determined. This can be achieved by a digitizer tablet. First the tie areas are selected and marked on the paper prints manually. This procedure is very similar to the traditional procedure of aerial triangulation point measurement. The only difference is that here no actual point but a small area of approximate 2 to 4 mm diameter will be selected and marked, in which the operator thought it would be suitable for the tie points to locate. Corresponding conjugate tie areas in the overlapping neighboring photographs are marked under a mirror stereoscope. Conjugate tie areas in different photographs are given the same number, but are stored in different paths in the computer. The path name is adopted from the strip number and the photo number. By this naming method, the search of the corresponding tie areas in different photographs is simplified. The marked paper prints are then put on the digitizer tablet and digitized manually to get the approximate photo coordinates of each tie area. The photo coordinates are then transferred to the RS1 scanner for driving the CCD camera.

In RS1 the positive film is used for scanning. First the fiducial marks will be digitized and matched to get their reseau coordinates for calculation of the transformation parameters between the reseau coordinate system and the photo coordinate system. Various matching methods can be selected for determining the center of the fiducial marks, like centroid of gray values, template matching, Foerstner operator etc., also manually measuring by the cursor is possible. After the transformation parameters are calculated, the CCD camera can be driven to each individual tie area according to the photo coordinates and that area will be digitized into pixels. Since the patch size which can be digitized at one time is very small and the marking of the corresponding tie areas in different photographs is relatively rough, we have to digitize for each tie area at least 4 connecting patches to form a larger square of doubled side length to ensure that there will be enough overlap between different photographs.

The 4 patches are joint together through the reseau crosses. Since the pixel coordinates (row, column) of the reseau crosses are not integers, during the connection a resampling process is necessary. After joining, the central part encompassed by the four outer reseau crosses is cut out for subsequent matching. The reason for cutting out only the center part is to avoid geometric distortion which might exist in the border area of each patch, because the transformation is based on the four reseau crosses in the patch and what ever outside the area enclosed by the four crosses is less accurate than inside. The center part has the size of 512x680 pixels.

4. Searching for Matching Windows in the Tie Area

From all conjugate tie areas, one will be selected as the master area, the rests are the slave areas. The slave areas will be matched to the master area. Each time only one slave area will be matched to the master area. In each master tie area, a number of places should be selected as the potential locations of the TPs. The exact location of a TP is determined by the Foerstner operator. In order to reduce the searching time, the search for TPs is done in the image pyramid. For every tie area the image pyramid is built by simply averaging 2x2 pixels into one single pixel. From the original image upward, three higher levels will be built up. The highest level has only 64x85 pixels.

In the highest level of the image pyramid of the master area, the Foerstner operator will be used to find the interest points (IP). All points which have the w value greater than 0.5 times of the mean w in this tie area, and the q value larger than 0.5 will be marked as an IP. Maximum 20 IPs will be retained, the rests will be neglected. The w value is a measurement of the error ellipse of the matched position and the q value is a measurement of the roundness of the error ellipse (Foerstner 1987). Going from these IPs, their corresponding locations in the lower levels will be traced down the pyramid until to the lowest level (with the highest resolution as originally digitized). Since these locations represent interest points in the highest level, which do not necessarily represent interest points in the lowest level, new IPs will be searched again in the lowest level. But we don't have to do blind search over the whole area, only in the vicinity of these traced locations the new IPs will be searched. In this way, it is guaranteed that the IPs are separated with enough distance. The search is done by opening a window surrounding these locations and running the Foerstner operator again using the same criterion as before. This time, again several IPs will be found. But we need only one. Therefore the one with the maximal variance in gray value is selected as the final aerial triangulation point (TP).

After the TPs in the master tie image have been determined, their corresponding approximate locations in the slave tie image must be found for serving as initial starting positions for the fine LSM matching. The search for their corresponding locations in the slave tie image is also done through the image pyramid. First, the location of the TP just found in the master tie image will be traced up to the highest level, from there the corresponding location in the same level of the slave tie image will be determined by finding the maximal Normalized Cross Correlation (NCC). Than these locations will be traced down through each level of the slave tie image by finding the maximal NCC to the corresponding master window in the same level. Since the tracing is done from one level down to the other, which means the initial position in each level is fairly accurate, the search window needs not be very large, except for the highest top level where we have no information for the initial position and a blind search in the whole image is necessary.

While going through the pyramid levels, a threshold of 0.65 is set for the NCC value in order to avoid wrong matching. Whenever this threshold can not be passed, that TP will be abandoned. If at the end there is less than two points left, the system will issue a failure message and switch to the manual selection of the interest windows both in the master and in the slave images. The matched position in the lowest level of the slave image will be considered as the conjugate position to the TP in the master image. Its coordinates go into the next stage of fine matching. The searching procedure can be illustrated by Fig.1. The arrows indicate the direction of tracing.

5. Matching Strategy

Based on the initial matching position obtained in the previous step, the fine LSM can begin. But by trying to find a proper window size for the LSM, we have found out that there is no such thing as the best window size. Different window size will give different converging position (or no convergence at all). Some times when one window size failed to converge, by changing the window size it could come to a convergence. Therefore we gave up the effort to find a best window size for all cases. Instead, we let each point to be matched by several different window sizes and try to find the best result from them.

We know that unless the LSM diverges, it will always give a result (the two shifting parameters between the windows). Although the posterior sigma naught reveals some knowledge about the quality, but its power for judging the correctness of the result is too weak. Therefore we use the NCC value as a check. Prior to the begin of the LSM, there was a NCC value for that initial position as computed in the previous step. After the LSM converges, new NCC value can be calculated between the target window and the resampled matched search window. The relationship between the master target window and the slave search window before and after LSM is illustrated in Fig.2.

We have found out that by setting some thresholds and conditions for these values, the more reliable and accurate result can be selected from all the results of different window sizes.

A series of window size 35x35, 39x39 and 43x43 will be used for the LSM. (The window size can be changed of course to fit the different conditions like different image scale, pixel size and image content, etc.. Since the pixel size is very small in our case, we have started from the 35x35 window size.) If the NCC value of the initial position found from the previous step is called C1, and the NCC value after the LSM is called C2, from the matched results of all possible window sizes, only the one which satisfies the following conditions will be selected as the final result:
1. Its C2 must be greater than 0.75.
2. Its C2 must be greater than or at least equal to C1.
3. Its C2 must be the greatest among all window sizes.
4. If more than one window size satisfy the above 3 conditions, the one with the largest window size shall be selected.
When no window size satisfies these conditions or even the LSM diverges, the system outputs an failure message and switches to manual selection of target and search window positions.

6. Test Results

The test block has 4 strips, 26 photos and covers an urban area with many buildings. The photo scale is 1:5000. For each tie area approximately 20 TPs are selected. The size of windows in each pyramid level and the threshold value of NCC for finding the correspondence are listed in Tab.1. The thresholds used in the dynamic window LSM are 0.65 for C1 and 0.75 for C2. For each tie area at most 5, at least 2 triangulation points should be found. Two points are the minimum to provide sufficient reliability (error detection) for the subsequent bundle block-adjustment. Tab.2 shows the number of triangulation points actually matched in the tie area and the number of tie area sets corresponding to them. All conjugated areas referred to the same terrestrial position form a set. A TP in a set of tie areas is considered as successfully matched only when it is matched in all tie areas in that set. When it can not be matched even only in one area, the whole set will be declared as failed. From Tab.2 we can see that the number of tie area sets which have at least 2 matched points is 69. There are 4 sets in which no point could be matched, and 1 set with only 1 point matched. These five sets are considered as not successful. There are total 74 sets, therefore the success rate of matching is 93%. For those sets with less than 2 matched points, manual selection procedure were used. There are total 335 TPs in the 74 sets of tie areas. The total number of point measurements are 1057. They will enter the bundle adjustment with minimum constraint. 162 from them were found wrong and discarded during the adjustment so that the correctness rate is 85%. The posterior sigma naught from the bundle adjustment with minimum constraint is 7µm. Since the purpose of this test is to see the reliability and success rate of the matching, we have not done any thing to eliminate systematic errors, so that the sigma naught does not represent any actual accuracy of the matching.

7. Conclusion

As long as only measuring of aerial triangulation is concerned, there is no need to digitize the whole photograph. For most photogrammetric projects, the forward- and side-overlap are very regular as specified in the flight contract. In such cases the aerial triangulation points always locate at the so called Von Gruber positions. Therefore only a very small area needs to be digitized for the aerial triangulation. In our case we used the Rollei RS1 scanner to digitize such small areas for automatic finding and measuring the aerial triangulation points. Since the data amount of pixels is very small, the whole procedure can be done on a PC. The RS1 itself is much cheaper than large format high precision whole frame scanners, so that our solution can be called as a low-cost solution.

The only drawback of digitizing only a small area is that it has to be precise enough to assure that there will be enough overlapping in different photographs. This is achieved by manual scanning. Therefore we call this solution the semi-automatic measuring of the aerial triangulation points as in contrary to the full automatic solution like the MATCH-AT from the INPHO Stuttgart or the DCCS.

The test results show that there is no doubt about the applicability of this system. In few cases when no point can be found at all or the matching is wrong, it always can be solved by human intervention. One big problem is that the radiometric response of the CCD of the RS1 is not stable enough, so that great efforts have been made to reduce such errors.

REFERENCES

Foerstner, W. 1987:
A Fast Operator for Detection and Precise Location of Distinct Points, Corners and Center of Circular Features. Proceedings of the intercommission conference on Fast Processing of Photogrammetric Data. Interlaken, Switzerland. pp.281-305

Helava, U.V. (1987);
Digital Comparator Correlation System. Proceedings of the intercommission Conference on Fast Processing of Photogrammetric Data. Interlaken, Switzerland. pp.404-418

Luhmann, T.; Wester-Ebbinghaus, W. (1986):
Rolleimetric RS - A new system for digital image processing. Symposium ISPRS Comm.II, ISPRS Vol.26/2, Baltimore.

Tsingas, V.:
Automatisierung der Punktuebertragung in der Aerotriangulation durch mehrfache digitale Bildzuordnung. Dissertation, Deutsche Geodaetische Komminsion, Reihe C, Heft Nr.392, Munich, Germany.

Table 1. Window size and correlation threshold during point matching

	Original image	First level	Second level	Third Level
Target window	35 by 35	29 by 29	23 by 23	17 by 17
Search window	47 by 47	41 by 41	35 by 35	64 by 85
threshold	0.65	0.65	0.65	0.65

Table 2. Number of tie area sets in which 0 to 5 TPs are successfully transferred

No. of TPs transferred	No. of sets
0	4
1	1
2	3
3	0
4	2
5	64

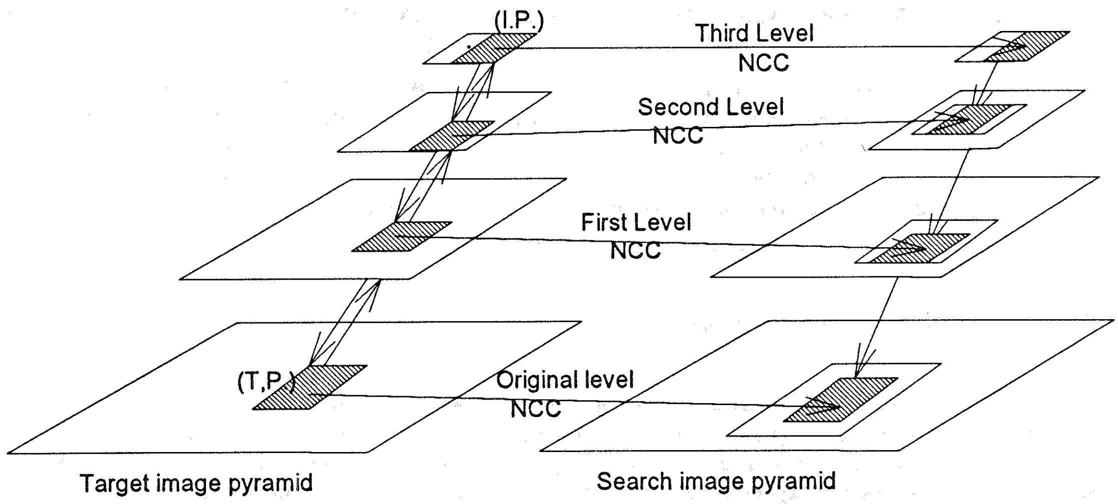

Fig 1. Tracing of I.P and T.P. through the image pyramid

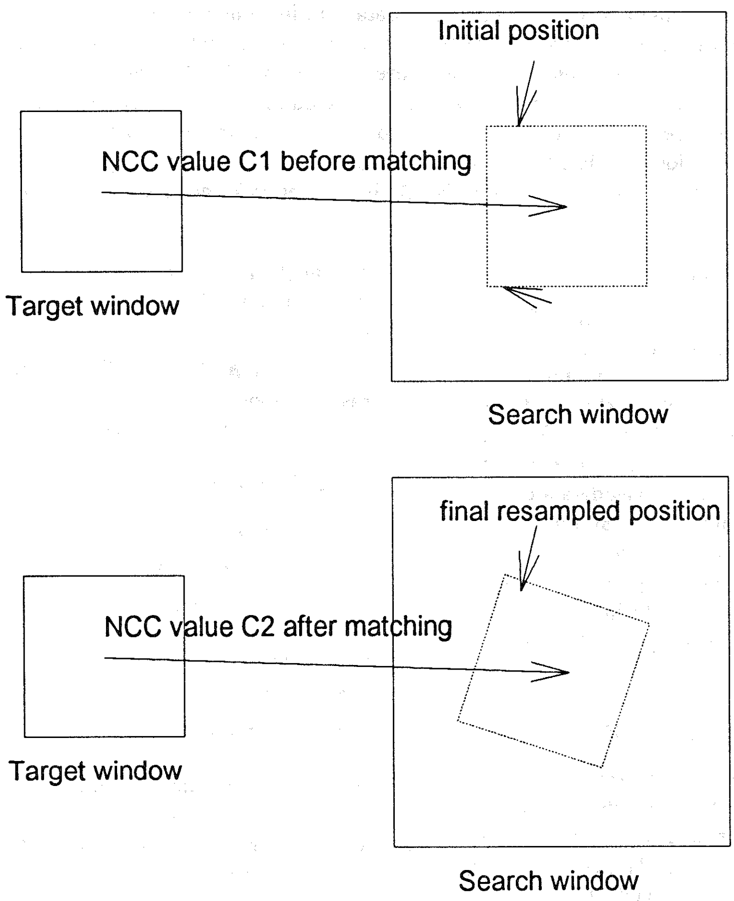

Fig 2. Relationship between target and search window before and after LSM.