CIRCULAR IMAGE BLOCK MEASUREMENTS

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ABSTRACT

At the moment, more and more rapid 3D documentation and less expensive measurement methods are required in photogrammetric reconstruction tasks. One considerable alternative will be methods utilizing video recording implementation. In this paper we will show a method based on continuous video recording sequences and freenet type estimation. The system is designed to be semiautomatic and to be used by non-photogrammetrists without knowledge of photogrammetric planning and geometrical aspects of imaging.

In this paper, we will concentrate on theoretical background of the method and especially on parameterization of the estimation problem. Results of simulated tests of image block formation will be presented. The main goals of tests are to verify the stable conditions for circular image block formation and solve the extent and goodness of scale measurements to be required in image block formation.

1 INTRODUCTION

The demand of 3D scene models and to get them in a fast and relatively easy way has increased lately. The consequence is that more automatic methods in image measurement systems are required as also that the imaging system has to be well controlled. By using retro or more preferably coded targets, the efficiency of the measurement systems can be improved drastically. Although the time spent for preparation; targeting and planning the imaging configuration; is considerable. Often the case is that we have numerous objects of the same kind and we can plan the imaging configuration only once. Then we only have to target the object and refine the measurements respect to the datum.

In a case we have a unique modelling task, we have to create a co-ordinate system, plan the camera positions and possibly do targeting before we get to the measurement part of the system. Planning the camera configuration might take time, as we have to design the control point distribution and camera positions respect to the object very carefully in order to achieve the required accuracy. Cause all these parts conflict each other, we have to approach this problem iteratively. The design of the measurement system can be divided into ZOD, FOD, SOD, and TOD levels of planning according to Fraser (Fraser, 1989). This type of procedure requires experience and is hardly a job of non-professionals.

To meet the first requirement of fast and relatively easy ways of modelling, we have to develop methods that are reasonably automatic and can regulate the imaging geometry in order to fulfil the requirements of the modelling accuracy. The system has to be easy to operate by non-professionals and measurement conditions have to be controlled so that the imaging geometry will be sufficient for the modelling purpose. The system should take care of the imaging geometry and the modelling accuracy even when the operator does not understand the concept of accuracy in photogrammetric 3D modelling.

The method presented here will produce a reasonably good geometry for 3D measurements from multiple images. The idea is to construct an image block like in a conventional close-range photogrammetric method. Instead of defining the best positions of camera stations for the measurements, the camera positions will be constrained to lie on the path of the circle. It is also required that such a circular image block will be closed i.e. first and last image have to overlap. The imaging geometry may not be optimal for the task, but it certainly will give a sound basis for estimating the accuracy of the resulting model.

2 IMAGE BLOCK CONSTRUCTION

In our imaging design the images will be taken in a very controlled way. The camera will not be attached to camera tripod directly, only one end of a straight rod will be attached to it and the camera will be attached to the other end of the rod (**Figure 1**). Images will be taken while turning the rod around the tripod during the turning sequence until a whole circle is made. The subsequent images should have enough overlap since the individual image position will be estimated in a freenet estimation based on tie point observations between subsequent images.

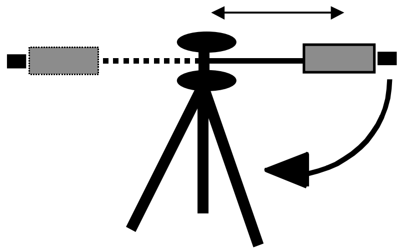

Figure 1 Imaging geometry in a circular image block

It is important that the circular image sequence; block; is closed since the co-ordinate system will be created on a site. That means no control point network nor measurements for camera poses are required. The center point of revolution will be determined as an origin for the measurements. Some scale measures may be though required. The restricted imaging arrangement restrains the projection centers of each camera position to lie on the same plane and within the same distance **r** from the revolution center.

For the 3D measuring point of view this circular image block is perhaps not perfect for the task, especially if the camera is looking outwards from the revolution center and the consecutive camera positions will have diverging optical axes. The solution is to turn the camera to the tangential direction of the circle (**Figure 2**).

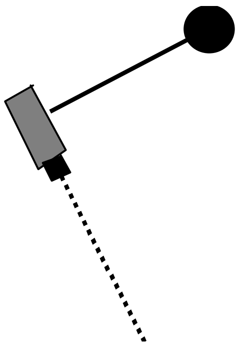

Figure 2 Camera turned to tangential direction

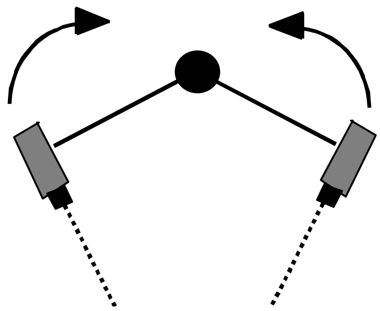

Figure 3 Two co-centric image blocks

By constructing two such circular image blocks on the same tripod position and changing the orientation of the camera at the end of the turning rod, we will have two co-centered image blocks with same co-ordinate system and image pairs with good imaging geometry (**Figure 3**). Images of an image pair will be at most two times as far as the length of the rod from each other.

If video camera is used we can use all the images in a sequence to reconstruct the object instead of selecting the images with best geometry. With this huge number of images we can substitute the lower quality of images to some extent. In the object reconstruction part we can use parametric model estimation directly from image observations. By involving parametric reconstruction method we can further reduce the effect of image noise on our results.

This kind of approach is applicable in such modeling tasks where you do not have any reference system nearby or the camera constellation is difficult to design or build.

2.1 Estimation problem, Approach I

We can see the estimation problem as **n+1** number of relative orientations, or even **n** number if we include relative orientation between first and last image. By choosing the model of independent stereo models we can avoid resolving the object point unknowns. That is good since we are primarily interested in image orientations in an image block. Alternatively, we can end up using the bundle block estimation and applying collinearity condition. Then we will have **n** number of exterior orientations to be solved.

In both cases we have a datum what is insufficient. We can apply freenet type solution and use minimum norm solution or we can fix some parameters in order to get datum become sufficient. Fixing the x-axis of a defined co-ordinate system in the direction of the first image projection center solves this problem.

As the camera is rotated around the origin, the rotation angles will change respect to the co-ordinate system but the angle between the image plane and position vector of the projection center will stay constant. By applying this knowledge and the fact mentioned earlier that all projection centers lie on the path of the same circle, we can set constraints to stabilize the estimation process.

$$|P_i| = \mathbf{r} \tag{1}$$

or

$$\sqrt{X_i^2 + Y_i^2 + Z_i^2} = r \tag{2}$$

Equations (1) and (2) state that all projection centers are at the same distance from revolution center, but this does not say anything about them lying on the same plane. This can be expressed by setting a constraint between projection centers and a normal vector η of the plane.

$$P_i \bullet \eta = 0 \tag{3}$$

We can also consider η as a new parameter vector to be estimated. By giving a big weight in LSQ estimation for this observation equation we force the system to retain this condition. The constant angle between the position vector of the projection center and the optical axis of the camera can be forced by adding in estimation a constraint like:

$$R_i \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \bullet \frac{P_i}{|P_i|} = \mathbf{constant} \tag{4}$$

By using independent stereo models and coplanarity condition we will have in LSQ estimation **n*5+3** unknown parameters (η is included in unknowns) plus **n*2** constraint equations. With bundle ray model we will end up to **6*n+3** plus **m*3** unknown parameters, where **m** denotes the number of tie points. With stereo models the condition equation will take the form (Mikhail, 1976):

$$\begin{aligned} A(l+v) + Bx &= d \\ Cx &= g \end{aligned} \tag{5}$$

and with bundle of rays based on collinearity condition, the equivalent form is:

$$\begin{aligned} Ax &= v + l \\ Cx &= g \end{aligned} \tag{6}$$

2.2 Estimation problem, Approach II

The image block estimation based on bundle of rays model can also be written by using different set of parameters. As we are not using any exterior control points and we are constructing our own co-ordinate system we can make some assumptions. As we have already defined origin to be the revolution center and x-axis lying at the direction of the first photo projection center, we can also state that projection centers of the camera will lie on a plane parallel to a co-ordinate plane. We can choose the y-axis to point upwards so the all projection centers will lie on the xz-plane. This is due to avoid situations where the denominator of the collinearity condition will go to zero. Now we can fix the y-co-ordinate of all projection centers to be a constant and express the x- and z-coordinates in a polar coordinate system:

(7)

$$\begin{cases} X_i = r \cdot \cos\alpha_i \\ Y_i = \textbf{constant} \\ Z_i = r \cdot sin\alpha_i \end{cases}$$

Now we do not need to put any constraints to force parameter values of the projection centers to lie on a plane nor to be in a distance of **r** from the revolution center, cause all this information is included in equation. What we have not yet included in the model is the constant angle between optical axis of the camera and the position vector of the projection center. In a special case where we have zero tilt (ω) and spin (κ) angles, our rotation matrix differs from the first camera rotation matrix $\mathbf{R}_{\omega,\phi,\kappa}$ only by the difference $\mathbf{R}_{\omega,\phi-\alpha,\kappa}$. Note that the angle values in ϕ increase in the opposite direction than α values. In practice this kind of configuration is quite easy to arrange. But more generally, the rotation of camera by α_i angle can be expressed in 2D rotation on plane:

(8)

$$R_{\omega_i,\phi_i,\kappa_i} = R_{\alpha_i} \cdot R_{\omega_0,\phi_0,\kappa_0}$$

where,

(9)

$$R_{\alpha_i} = \begin{bmatrix} \cos\alpha_i & 0 & -\sin\alpha_i \\ 0 & 1 & 0 \\ \sin\alpha_i & 0 & \cos\alpha_i \end{bmatrix}$$

Since the rotation angles ω_i, ϕ_i and κ_i depend on the first photo orientation matrix by the angle α_I, there is no point to estimate those dependent parameters. Instead, we should linearize the nonlinear observation equation respect to first photo rotation angles, radius of the circle **r** and separate α_i angles. Now, the total number of photo unknowns will be **4+n**. The effect of one image observation on normal matrix **N** is depicted in **Figure 4**.

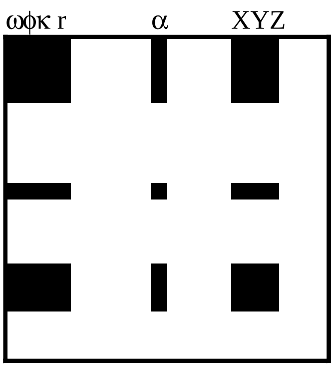

Figure 4 Effect of one image observation on normal matrix

3 IMAGE BLOCK ESTIMATION

The model used is based on image bundle blocks and collinearity condition. Another alternative would have been to use independent stereo models as primary computation units. It is true that block adjustment based on stereo models and coplanarity condition do not include unknown 3D object points in estimation, which was stated earlier. But geometrically thinking those unknown points are still there, and in a case of bundle of rays you can always eliminate the unknown 3D points out of a LSQ type estimation like (Mikhail, 1976):

(10)

$$A = \left[A_1 A_2 \right]$$

(11)

$$N = A^T A = \begin{bmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{bmatrix}$$

$$\begin{bmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$$

The normal design matrix **A** is partitioned in two sub matrices where the columns of the matrix represent the coefficients of the photo orientation or 3D point co-ordinate values as depicted in equation (10). The normal matrix **N** can then be reduced to the size of the sub matrix $\mathbf{N_{11}}$ of the original normal matrix as shown in equation (11) (Mikhail, 1976).

(12)

$$\left(N_{11} + N_{21}\, N_{22}^{-1}\, N_{12} \right) x_1 = b_1 - N_{21}\, N_{22}^{-1}\, b_2$$

By using the linear model we do not need to re-eliminate the 3D point unknown parameters, but since we have chosen to use a nonlinear type model we are forced to resolve corrections also to approximations of point unknown parameters. The re-elimination is depicted in equation (13).

(13)

$$x_2 = N_{22}^{-1} (b_2 - N_{21} x_1)$$

The idea of eliminating the unknown point parameters from the estimation might be rather beneficial. Since we are going to have numerous images included in a single circular image block, we will also most likely have numerous unknown 3D points. One additional photo increases the number of unknown parameters by one, but one additional 3D point increases the number of unknowns by three. As the normal matrix **N** can be updated by observation equations iteratively, there is no need to construct the design matrix **A** at all. Also, the elimination of unknown parameters can be done iteratively. So the elimination can be done point by point. Though we have to take care that all observation attached to that point are updated consecutively to the sub matrix of $\mathbf{N_{12}}$ and $\mathbf{N_{22}}$. After this the reduced normal matrix can be updated by using equation (12) and we can continue by processing the observations of the next point. The number of steps to construct the reduced normal does not differ much from the number of steps used to construct the original **N**. Calculating the re-elimination increases the number of steps but the computing time in this task is tremendously short compared to time spent for computing the LSQ solution for a large normal matrix **N**.

3.1 Aspect of geometry

In chapter 2 we introduced the camera configuration of a circular image block. We mentioned that point intersection would be poor unless we do not use image observations from a second co-centric image block. The difference between these two co-ordinate systems is only an angle between their x-axes. So the angle can be estimated from observations of common points.

When thinking about single block estimation we can find that the same geometrical problem appears. The angle of image rays for the unknown 3D tie point will be rather small (**Figure 5**). So the position accuracy for such a point is questionable. Even though those tie points are not going to be used for modeling purpose, the unreliability of those observations also affects camera orientations.

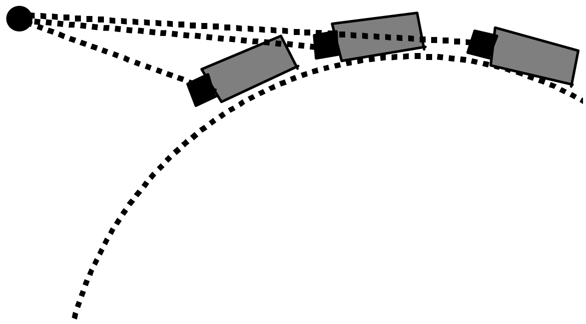

Figure 5 Poor intersection geometry.

Based on this aspect we should estimate both image blocks simultaneously. This way we can get good observations from convergent images. The number of additional unknowns respect to photo parameters is $\mathbf{5+n_2}$. The first five unknown parameters consist rotation angles of the first camera position on the second block, radius $\mathbf{r_2}$ and angle β between x-axes of first and second blocks. The rest $\mathbf{n_2}$ unknowns are β_i angles from first camera position of the first image block. The number of tie points does not need to increase much as both sequences will include more or less the same scenery.

As we will construct our own coordinate system and we do not have any exterior knowledge we have to have a scale for our measurements. Though in a closed image block we do get the scale without any auxiliary measurements. The scale will be based on the interior orientation of a calibrated camera. This scale derived from interior orientation might not be the most reliable and auxiliary distance measures will be necessary to support our estimation process. Distance measures can be included in estimation as constraint equation or as a normal observation with a high weight. We chose to use the later alternative.

4 SIMULATION

In order to analyse the precision of the image block construction we created a simulated situation. The point set presenting the tie points was evenly distributed about 5m from the revolution centre. There were altogether 240 points in a set. Thirty photos were taken evenly spaced on the circular trajectory. The camera model resembles a video camera type device with resolution 572 x 720 (PAL standard). The camera constant was 900 pixels.

We created the observations by projecting 3D points on the focal plane. The camera positions were equally spaced on the circle with radius of 0.3m and orientations were calculated according to equation (8). The distance between subsequent camera poses in a single block was 62mm and angular difference 12 degrees. For the 3D point initial values we generated some error to evaluate how sensitive the system is to initial values. We found that initial values from few decimetres up to a meter from correct values were still acceptable.

We tested the case where only one circular block was present in estimation and a case where both image blocks were estimated simultaneously. Also cases with and without an auxiliary distance measure were tested. A couple of times with distance observations we came across a situation where iterations began to divergence when distance measure was weighted too much. The reason was that the system corrected the parameter values too much, so that the angle α_i was greater than the angle α_{i+1}. The situation was unbearable and caused the system to fail. In order to avoid such a situation we must take care that subsequent camera poses cannot change places during the estimation. Adding the following constraint will do this:

$$\sum_{i=1}^{n-1}\left|\alpha_{i+1}-\alpha_i\right|+\left|\alpha_1-\alpha_n\right|=2\pi \qquad (14)$$

5 OBJECT RECONSTRUCTION

What are the advantages of this kind of image block formation? The construction of camera configuration is very well controlled and with sensible parameterization the solution of the problem can be stabilized. The result is numerous camera poses with known position and orientation in the same co-ordinate system. Now we can have multiple observations to one object point as in the traditional camera configuration the point could be seen only on two images. Also, with this geometry of the image block we can reach nearly equal positioning accuracy in all directions.

This kind of imaging configuration is applicable for tasks where the object is surrounding the camera station. Like in caves and other inner space measurements. Also measuring tasks where no exterior co-ordinates system is present are favourable for the presented method.

The great number of images is partly an advantage and party a disadvantage. The huge amount of images needs a lot of processing but on the other hand numerous observations can improve the accuracy of 3D measurements. Because the imaging is performed in a controlled way we can take advantage of this (Heikkinen, 1995) (Heikkinen, 1996). The knowledge of the turning direction of the camera lets us search the correspondent point on the next image at the defined direction on image. Also the fact that subsequent images have only few degrees of difference on orientation angles gives us an opportunity to use area based signal matching, which would not normally work with divergent images and highly three-dimensional objects.

The object modelling by using parametric models has been proved to be beneficial when we have a lot of observations (Heikkinen, 1994). Parametric models include the geometric properties of the object in a very compact form. That is why it is very important that we choose the right parametric model for the reconstruction. With the parametric object modelling from images we understand the procedure first introduced by Mikhail and Mulawa as Linear feature based photogrammetry (Mulawa, 1989) (Mulawa-Mikhail, 1988). In this procedure the estimation of object parameter is based directly on image observations. Traditionally the object points are measured first and after that the object parameters are estimated on these resolved 3D points. With linear features based methods the edge measurements are used directly to estimate parameter values of the object.

6 FORESTRY APPLICATION

Our pilot application area belongs to the field of forestry. In Finland there is a long tradition of forest inventation. From the first forest inventation a systematic sampling method has been used. The sampling method called “relascope sampling”, also known as Bitterlich sampling, has been the main method in field measurements. The forest volume estimation method is based on theory of the stochastic processes. Even though the satellite image and laser scanning measurements are substituting field measurements nowadays, there is still need and place for them. New airborne methods give good estimates of tree heights, but the accuracy of tree stem measurement is still quite poor.

The observations needed in point sampling on field measurements are the relative distances of tree stems from the measuring centre. This means that we have to measure the distance and the diameter of the stem included in the sample. Those trees are included in the sample whose viewing angle is larger or equal to the selected angle α as depicted in **Figure 6**.

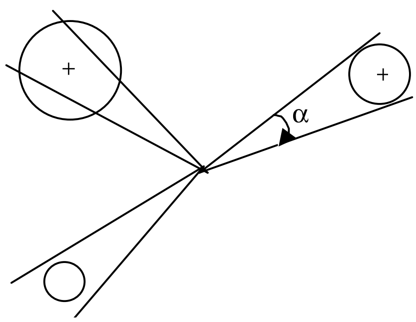

Figure 6 Relascope sampling method

Currently the measurements are done by using measuring tape. Our goal is to apply instead this presented method to measure the stem distances and diameters from the plot centre. A parametric cylinder or cone is going to be used for estimating tree stem volumes from multiple images.

7 DISCUSSION

In this paper we have shown the theoretical background of circular image blocks estimation. With simulated data we have been able to prove the convergency of the system. Further tests will though be required to discover the full cabability of this kind of imaging system. Especially in photogrammetric intersection, the potential of this system is really worth of investigation. The presented system is one additional tool for photogrammetric measuring systems, designed especially for tasks and applications where traditional methods are too unflexible and heavy to be used.

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