HIGH PRECISION DEM GENERATION FROM SPOT STEREO IMAGERY BY OBJECT SPACE LEAST SQUARES MATCHING

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Abstract:

For automatic DEM generation from multiple view SPOT imagery with high precision, an approach of "Refinement from Coarse" is proposed. In the coarse DEM generation stage, in contrast with the traditional methods which match at intensity level in image space with the signal processing technique, the concept of Knowledge Engineering is used to perform high level Feature Matching by Property List and String Matching for Correspondence analysis with high reliability. In the refinement stage, the Object Space Least Squares Matching method, which is the most rigorous method from a theoretical viewpoint, is proposed for coarse DEM refinement. This method is different from the traditional two-step approach which matches the corresponding point in image space first, and then determines the DEM by Space Intersection; this method is improved by back mapping the image data into object space to get object reflectance D(x,y) with referring the object surface Z(x,y), and perform matching in object space. It is simultaneously to determine two functions in the object space: the terrain relief Z(x,y) and the terrain reflectance D(x,y) in one solution with least squares adjustment iteratively. The disadvantages of matching in image space which the multi view image of the same object has different geometric or reflectance distortion can be avoided. It's flexibility allows the user to handle more than two SPOT multi-view images in one solution, which increases accuracy and reliability as well. It is good for SPOT images which offer the resolution with 10 meters groundel size only.

Key Words: DEM, Correspondence Analysis, Property List, String Matching, Object Space Least Squares Matching.

I. INTRODUCTION

The generation of a GIS for a 3-D object oriented data base is required urgently in many countries. The automatic extraction of 2.5-D information from SPOT stereo images is, potentially, an efficient and economic way. Some on-line (real time) commercial systems have appeared in prototype, but the methods of the off-line system for reconstructing the earth surface with high quality and acceptable economy must be researched and further developed still; We want to establish a system for generating DEM with high accuracy / high quality / high reliability with the support of the method of Object Space Least Squares Matching. It will then offer good fundamental 2.5-D information to GIS for multi-purpose applications.

2. BACKGROUND PROBLEMS

2.1 SPOT Satellite Imagery

Since the SPOT imagery is acquired by push-broom scanners, the imaging geometry is different from the conventional central perspective photographs with frame camera, and the orbit parameters require simulate dynamic modelling. For solving the inverse camera model problems, the point in issue is how to determine the orientation parameters of each scan line with sufficient accuracy (e.g. improving the accuracy of Tie Point measurement/transfer and best pattern of Ground Control Point distribution) and at lowest cost (e.g. minimum number of Ground Control Points). On the other hand, the CCT of SPOT not only presents imagery data, but also offers special on board auxiliary data, such as information about position, attitude, look direction, radiometric calibration of scene/sensor [SPOT User's Handbook, 1988]; how to fully use this information for obtaining benefits in Aerial Triangulation (A.T.) and DEM generation stage must be considered in every phase of image data processing.

2.2 Knowledge Engineering

The existing methods of signal correlation and feature matching are limited for handling some special correspondence analysis problems, such as automatic generation of coarse DEM data by Linear Feature Matching. In order to plan and execute complicated sequence of operations and functions, we believe the methods of Knowledge Engineering should be used, and Correspondence Analysis will be based on object detection with geometric definition and object description by means of Property Lists [Mulder et al.,1988]. The selection / representation and use of proper knowledge is a central problem in research. A range of different knowledge representation techniques must be developed, along with a number of approaches to applying knowledge, which are concerned in the field of Meta-Level Knowledge.

2.3 Object Space Minimum Cost Matching

Traditional matching in Image Space has the shortcoming that the same object in multi-view images appears with different geometric distortions and radiometry. The geometric distortions are caused by the central perspective which produces relief displacement in the image; the tilt of the sensor (SPOT has off nadir angle from 0 to 27 degrees) causes tilt displacement in the image. As the multi-view SPOT images are taken at different positions, at different times or under different illumination conditions, this produces different radiometry for the same object in different images. These geometric and radiometric differences produce matching failures or reduce the accuracy. Therefore, motivation for improved developments should come from the realization that all information in images is inherent in the object space, and the transformation of the matching problem from Image Space to Object Space leads to a unified and precise approach where all available knowledge is referenced to the same basis. Research has to be carried out into ways of how to model the surface of the terrain and its reflection which is suitable for matching properly and efficiently.
On the other hand, high accuracy can be obtained by using Minimum Cost Matching; e.g. the Minimum Euclidean Distance can be selected as the "Cost" in Euclidean space for similarity assessment. Because, in case the distance is small, the distance behaves as SIN function of the angle which is between the Feature Vectors for matching, it

may offer a sensitive measure for the distinction of extreme similarity in the primitive feature space. For the Least Squares Matching method, although the approach is completely different (i.e. not searching / comparing and selecting, but simultaneous Solution / determination of the unknowns), the basic idea is similar, namely, matching with very high accuracy to the degree of subpixel. This also has the advantage that Least Squares Adjustment is flexible which allows the users to perform matching with more than two images which can increase accuracy and reliability, and offers the theoretical quality estimation of the result as well.

3. THE SYSTEM COMPONENTS OF THE APPROACH

3.1 Preprocessing

3.1.1 Coordinate System Transformation
a) For mapping purposes, the coordinates of Ground Control Point (GCP) are offered in the Mapping System, because a SPOT image covers an area of 60 km x 60 km, hence the effect of the earth curvature can not be neglected any more. Therefore, a transformation from the Map Coordinate System to the Geographic System, and further to the Geocentric System is necessary. However, as the number of digits of coordinates in the Geocentric System is large, and a Double Precision is required in the data process to avoid truncation error, it is necessary to transfer the coordinates to Local Tangent Plane System to reduce the number of digits, and thus to save memory and speed up processing.

b) For using the on board data which are in the Geographic System / the Geocentric System / the Local Orbit Reference System / the Local Attitude Reference System, transformation to the Local Tangent Plane System is needed also.

3.1.2 Region Matching for DEM Generation and Change Detection Because the matching would fail within the homogeneous intensity region, or in the regions which the land cover has been changed when the satellite stereo pairs are taken with a long interval of time. Therefor, we use Conditional Rankorder Operator to smooth the intensity within the region first, then start Region Growing for image segmentation, the boundary of region can be extracted, and the shape can be described by ψ-s Curve, combine with other properties of region, such as the area, the position of gravity centre, etc., to form a Property List. The initial probability of region matching can be obtained by minimum cost function with the weighting properties in the list. Then the matching probability are being adjûsted by Relaxation Processes until the final conjugated region pairs are determined. The elevation of the region can be calculated with the conjugated region, and the change detection can be done by checking the mismatching regions and comparing the intensity between the conjugated region after region matching, the matching failure problem can be solved in these area [Lo,1992].

3.1.3 Aerial Triangulation (SPOT Orbit Determination)
a) On board data are used to define the overlap area of multi-view images and to choose the Tie Points at the proper position and evaluate / select the specific image properties (e.g. high contrast in X and Y direction) i.e. the most suitable features for matching required for automatic point transfer. After image segmentation is performed, the crossing of lines / edges are detected as GCP, and sufficient properties (structure representation) of GCP can be obtained for GCP identification by the Line-Based Structure Matching Method or Chain-Coding Matching. Moreover, on board auxiliary data and ground coordinates of GCP are also used to help automatic identification of GCP with property list for the correspondence analysis between maps/photos.

b) Establish the model for simulating the short arc orbit of SPOT as a function of time [Konecny et al.,1987] [Kratky,1988].

c) Extract on board data from CCT of SPOT [SPOT User's Handbook,1988] and use them as constraint (e.g. the attitude data) by the Pseudo Observation technique, in order to solve the problem of high correlation between orientation parameters caused by narrow FOV of SPOT (4.125 degrees only) [Chen & Lee,1989] [Shibasaki, el at.,1988]. At the same time, we try to reduce the number of unknown orbit parameters (e.g. simulating the orbital model for position by 2nd degree polynomial, and linear polynomial for attitude) resulting in a reduced number of GCP, and aim at finding out the best distribution of position of GCP in the adjustment of A.T. providing sufficient accuracy for later matching.

d) Application of Object Space Least Squares Matching with exterior orientation parameters as unknown; using on board auxiliary data as initial value, try to perform highly accurate Tie Point Transfer with interaction in adjustment of A.T. by iteration. This is the most difficult part to solve, because the known exterior parameters are the back bone of Object Space Least Squares Matching. If we treat them as unknown with on board data as initial values instead, we need to know how good the initial value should be to make the iteration convergent.

e) Empirical accuracy study of exterior orientation parameters from A.T. with the application of previously mentioned techniques, trying to get sufficient accuracy to meet the requirement of Object Space Least Squares Matching.

3.2 Coarse DEM Generation by Correspondence Analysis with Property List

a) There are several methods to enhance the Linear Features (Line / Edge) and then extract them; however, the original position and intensity of linear features should not be changed if the features will be used for matching (not for visual satisfaction) later. Therefore, a non-linear filter, such as Conditional Rankorder Filter [Mulder & Sijmons, 1984], can be selected for segmentation; thereby the enhancement of features is done by smoothing the background (suppressing the minor features / noise also) and keeping distinguished Linear Features in their original situation.

b) Reduce the 2-D search to a 1-D search during matching, by the resampling of image data into parallel line pairs (the approximate Epipolar Line pairs). This is, however, more difficult to apply to SPOT images, because the orientation parameters are a function of time [Otto,1988][Zhang & Zhou, 1989].

c) Apply a Gradient Filter to the image and detect the Linear Features with Zero-Crossing.

d) Property List Formation by collecting the properties of Linear Features such as Position, Amplitude and Shape of peak / valley in intensity profile along the parallel line pairs [Lo,1989], and the Orientation of Linear Features [Kostwinder el at,1988].

e) To offer the criterion for Correspondence Analysis, Cost Function Modelling is required by assigning different weights to the individual properties according to it's reliability and major/minor contribution to express the characteristic of feature. The weight can be assigned by prior analysis or by experiment with Trial and Error.

f) Between the conjugated parallel line pairs, the corresponding linear feature can be extracted by String Matching which selects the Minimum Cost as best matching, based on information from the Cost Function. For the conventional matching strategy, the Target Area of the left image is selected to search for the best match in Search Area of the right image only; the result may be different, however, if the matching is from right to left. The String Matching uses the mutually matching strategy which matches not only left to right but also right to left, then selects the real Minimum Cost among them as best matching with the marking technique for extracting them. It increases the reliability of the result. If we confirm the extracted linear features again by checking the continuation of linear features between neighbouring parallel lines, the reliability can be increased still more [Lo,1989]. The extracted corresponding linear features pairs can be used to generate coarse DEM, the major requirement of generating coarse DEM with high reliability is fulfilled.

3.3 Refinement of Coarse DEM Data by Object Space Least Squares Matching

3.3.1 The Illumination and Reflection Model for facet stereo matching There are three major phenomena of the reflection : Ambient reflection, Diffuse (Lambertian) reflection and Specular (Mirror) reflection. It describes the relationship of reflected radiance of a small facet of the surface, the specific viewing direction, the complex illumination of the scene and light reflecting properties of the material. (Weisensee,1988) proposed three models of light reflection which can be used for Object Space Least Squares Matching, they are derived from general model as follows:

$$L_R = L_{Ia} \circ R_a + \Sigma_n L_{In} \circ (\underline{N} \circ \underline{B}_n) \circ dw_{In} \circ (S \circ R_s + d \circ R_d) \quad (1)$$

- L_R : the reflected radiance cause by incident radiance of illumination
- L_{Ia}, R_a: the ambient component from half space L_{Ia} and the semi-spatial reflectance R_a
- $\Sigma_n L_{In}$: n light sources having irradiance L_{In}
- N : the surface normal
- B_n : the direction to light source n
- dw_n : the apparent solid angle of incident radiance from a particular light source
- R_d, d : the diffuse reflectance R_d and its fraction of proportion for diffuse reflectance
- R_s, s : the specular reflectance R_s and its fraction of proportion for specular reflectance

In our case, we can assume that there is only one light source (n=1,the sun) to be considered. The amount of light reflection which independently with the viewing direction is :

$$L_{Rd} = L_{Ia} \circ R_a + L_I \circ (\underline{N} \circ \underline{B}) \circ dw_I \circ d \circ R_d \quad (2)$$

the specular Component which is rare exist and can be omitted is:

$$L_{Rs} = L_I \circ (\underline{N} \circ \underline{B}) \circ dw_I \circ S \circ R_s \quad (3)$$

the relationship between recorded intensity G_i of discrete pixel i by the sensor and the reflected radiance from the terrain surface can be a linear transformation:

$$G_i = a + b \circ L_{Rd} \quad (4)$$

if the terrain surface is perfect ambient reflection, the first reflection model can be:

$$G_i = a_j + b_j \circ D_i \quad (5)$$

D_i is the reflected radiance of facet i, if the terrain surface is assumed as perfect Lambertian reflectance, the second model is:

$$G_i = a_j + b_j \circ \cos(\underline{N} \circ \underline{B}) \circ D_i = a_j + b_j \circ \cos\theta_i \circ D_i \quad (6)$$

the third model:

$$G_i = a_j + b_k \circ D_i \quad (7)$$

results from applying the transformation (4) to facets instead of windows. It means a_j is still valid for window j, the b_k applies to a bilinear height/reflection facet k respectively.

3.3.2 The principle of Object Space Least Squares Matching Back mapping of image data into object space to get object reflectance D(x,y) (image inversion) by referring the object surface Z(x,y) which is approximate at the beginning, and perform matching on the object surface. It simultaneously determines two functions in the object space: the terrain relief Z(x,y) and the terrain reflectance D(x,y) with Least Squares Adjustment iteratively [Wrobel,1988] [Helava,1988] [Ebner & Heipke,1988] [Heipke,1990]. By this way, the digital image matching, DEM generation and orthophoto computation have been combined into one approach.

The main principle of Object Space Least Squares Matching is as follows:

The basic Observation Equation of every pixel within the patch for matching by the Least Squares Adjustment is:

$$v = \check{D} * \cos\theta - D(\check{Z}, \breve{A}, \check{L}, \check{R}) \quad (8)$$

- v : noise or residual error in intensity
- $\check{D}$: the unknown intensity value assigned to one groundel
- θ : the angle between the surface normal and the direction of sun
- $D(\ )$: back mapping the image intensity value of corresponding pixel to the groundel.
- $\check{Z}$: the heights of N x M grid points (DEM) to represent the terrain surface $\check{Z}(X,Y)$ which can offer the height in any position by bilinear interpolation.
- $\breve{A}$: orientation parameters of the sensor
- $\check{L}$: illumination model
- $\check{R}$: object reflectance model

a) The influence of $\check{L}$ & $\check{R}$ can be simplified by local linear radiometric correction with offset $\check{S}1$ and gain $\check{S}2$ (But not for close range photogrammetry and large scale photo). Therefore, (8) can be:

$$v = \check{D} * \cos\theta - \check{S}1 - \check{S}2 * D(\check{Z},\breve{A}) \quad (9)$$

For the patch of first image, $\check{S}1$ and $\check{S}2$ can be assumed as constant, they are unknowns for the patch of second, third and further images.

b) For Point Transfer in A.T., $\check{Z}$ and $\breve{A}$ are unknowns also, expanding the nonlinear part ($\check{S}2 * D(\check{Z},\breve{A})$) of (9) to linear increments from approximate values: $(\check{S}1 , \check{S}2)_o = (0 ,1)$, we obtain:

$$v = \check{D} * \cos\theta - \check{S}1 - \check{S}2_o * D(\check{Z},\breve{A})_o - \check{S}2_o * [(\partial D/\partial \check{Z})_o\, d\check{Z} -(\partial D/\partial \breve{A})_o\, d\breve{A}] - D(\check{Z},\breve{A})_o\, d\check{S}2 \quad (10)$$

The coefficients indexed by o are calculated with the estimated values which will be updated during the iteration. Expanding the coefficient $(\partial D/\partial \check{Z})_o$ and $(\partial D/\partial \breve{A})_o$ of the design matrix:

$$(\partial D/\partial \check{Z})_o = (\partial D/\partial x \,.\partial x/\partial \check{Z})_o + (\partial D/\partial y \,.\partial y/\partial \check{Z})_o \quad (11)$$

$$(\partial D/\partial \breve{A})_o = (\partial D/\partial x \,.\partial x/\partial \breve{A})_o + (\partial D/\partial y \,.\partial y/\partial \breve{A})_o \quad (12)$$

Because $\partial D/\partial x$ and $\partial D/\partial y$ represent the gradient of the intensity, it can be used for a quality estimation (selection), and provide the different weights accordingly in Least Squares Adjustment.

c) In case of DEM generation after A.T.. The orientation parameters of sensor A are known already. Therefore, the observation equation for each pixel within the matching patch is:

$$v = \check{D} * \cos\theta - \check{S}1 - \check{S}2_o * D(\check{Z},A)_o - \check{S}2_o * (\partial D/\partial \check{Z})_o\, d\check{Z} - D(\check{Z},\breve{A})_o\, D\check{S}2 \quad (13)$$

If we want to obtain DEM $\check{Z}(X,Y)$ only, the unknown $\check{D}$ can be eliminated (Reduced Normal Equation) during the inversion of the normal equation to save calculation time.

3.3.3 The characteristics of Object Space Least Squares Matching

a) We perform the matching in Object Space instead of in Image Space, because the disadvantage of matching in image space would be that the multi view image of the same object would have different intensity or shape caused by different relief displacement / tilt displacement / different illumination situation / different reflection effects from different positions of the sensor relating to different relief of object etc., resulting in matching failure or poor accuracy.

b) High accuracy can be achieved by using the Minimum Cost Matching which is based on the Theory of Minimum Cost Sequence of Error Transformation. This method may select the Minimum Euclidean

Distance as the "Cost" in Euclidean Space for similarity assessment. Because the distances behave as SIN function of angle between the feature vectors in case the distance is small, it offers a sensitive measure for the distinction of close similarity in the primitive feature space. In the Least Squares Matching Method, though the approach of matching is totally different, the basic idea is similar (Min. Σvv <--> Min. distance), namely matching with very high accuracy to the degree of subpixel; it requires, however, a very good conjugacy prediction (coarse DEM). The commonly used Normalized Cross Correlation method provides a correlation function behaviour as a COS function [LO,1991]. This function has a flat peak at maximum similarity; therefore, to interpolate this function to get subpixel accuracy is hardly worth the effort.

c) When we use the unknown parameters to establish a mathematical model (Observation Equations) which can precisely describe the phenomena of observation/ sampling (e.g. the back mapping of intensity from image space to object space), the Least Squares Method minimizes the differences between the description model with actual model to determine the value of unknowns (when the observation equation is linear), or to update the estimated values of unknowns iteratively (when the observation equations are non-linear). Every pixel involved in matching can provide one observation equation; if redundant observations exist (the number of observation equations is more than the unknown parameters, i.e. the over-determined problem), the Least Squares Method is a good method to determine the value of unknown parameters even when the errors of observations are not a Normal Distribution. The principle of the Maximum Likelihood Method is identical with the principle of Least Squares Adjustment, if we have assumed that the errors of observations are a Normal Distribution. But unlike the Maximum Likelihood Method of estimation, the method of Least Squares does not require the knowledge of distribution from which the observations are drawn for the purpose of parameter estimation; however, for testing of hypotheses, we would require the knowledge of the distribution [Bouloucos,1989].

d) Least Squares Window Matching has been used in the two-step approach whereby matching in image space is performed to get the conjugated position first, then the Space Intersection is used to reconstruct the object surface [Ackermann,1984]. Its window size is limited to 20x20 pixels or 30x30 pixels; if the window is smaller than this, reliability is decreased, but if it is larger than this, accuracy will be poor because matching is performed on image space, and the geometry model is simplified [Rosenholm,1987a]. The improved approach unifies these two steps into one, and matching on object space. Back mapping of image intensity into object space to get object reflection D(X,Y)(image inversion) is done by referring the coarse object surface Z(X,Y), then perform matching on object surface and refine the coarse object surface iteratively. In addition to this, two functions in the object space, i.e. the object surface Z(X,Y) and the object reflectance D(X,Y) are simultaneously determined (considered) in one solution with Least Squares Adjustment; this is the reason why we consider this to be a more rigorous method than the earlier methods.

e) By referring the coarse object surface Z(X,Y), there are two ways to back mapping of the image intensity into the object surface in order to get the estimated object reflection D(X,Y). One is called Directed Pixel Transformation: it starts with pixel position (x,y) in the image; the Collinearity Equation with orientation parameters of its scanner is used to intersect the coarse object surface Z(X,Y) to get the position of corresponding groundel X,Y, and transfer the intensity of this pixel to it. However, the problem is that the groundels distribution on object surface after back mapping present a random pattern and they are different in different multiview images also; another shortcoming is that the height of these random position points needs to be interpolated to grid DEM but lose information. The other way is called Indirected Pixel Transformation: we start with a coarse DEM grid (X,Y,Z), and the Collinearity Equation with orientation parameters of the scanner is used to get the corresponding pixel position (x,y). Another problem arising from SPOT's Push Broom scanner is that the orientation parameters of each scan line are different (for a frame camera, it is the same in the whole image); therefore, if we don't know which set of orientation parameters we should use for transformation, we can not use the Collinearity Equation to get the corresponding pixel on the image and transfer its intensity (after resampling) to that grid point. If we can solve this problem, the Indirected Pixel Transformation is better than Directed Pixel Transformation, as the weighted average of pixel intensities which are obtained from multi-view images according to the same grid point, can be used as the estimated object reflection D(X,Y), and the weight is assigned according to the slope of ray.

f) The Least Squares Matching method is capable to handle any number of images over two, e.g. the Triplet, as well as images scanned in various spectral bands simultaneously. It increases both reliability and accuracy of the result [Shibasaki & Murai,1988].

g) The traditional method uses windows of pixels for matching to determine a single point (usually the middle point) only, but Object Space Least Squares Matching uses a window of pixels for matching to determine multi-points in a grid pattern DEM in one solution. If preprocessing provides prior knowledge about the quality of matching windows (e.g. the gradient of intensity), we can assign different weights accordingly (e.g. give the high contrast pixels a larger weight) in the Least Squares Adjustment. This means that we require the high contrast pixels to offer a larger contribution for the decision making which helps to avoid making the wrong decision in the homogeneous part of the image. Thus, a combination of advantages from Feature Based Matching and Area Based Matching can be obtained. DEM determination executed in this way is thus called Multi-Point Matching, and offer higher reliability [Rosenholm ,1987b].

h) Robust Estimation techniques can be applied in Least Squares Adjustment to get rid of noise as a gross error of sampling (observation).

i) The Least Squares Method provides theoretical quality estimation of the matching result based on statistics theory. It also offers useful information for cleaning gross errors in DTM data in the postprocessing stage as quality control, as well as for using the DTM data in GIS [Day & Muller ,1988].

j) The grid DEM is separately generated patch by patch with the quality estimation. The aggregation of the whole DEM can be done, e.g. by means of the Finite Element Method, with a quality improvement of DEM in the last stage. [Xiao et al.,1988].

4. SUMMARY

4.1 Summary of the Matching Algorithms and the Selection of Approach

There are many matching algorithms that can be used; we summarize the relevant algorithms, and indicate those selected and applied in this system with the mark of ***.

(a) Information for Matching:

*** Intensity-Based
*** Feature-Based (Property-Based)

(b) Criterion for Similarity Assessment:

* Angle between Matching Vectors:
COS Function --->
Less Accuracy/ High Reliability
*** Distance between Matching Vectors:
SIN Function(in small distance) --->
High Accuracy / Low Reliability

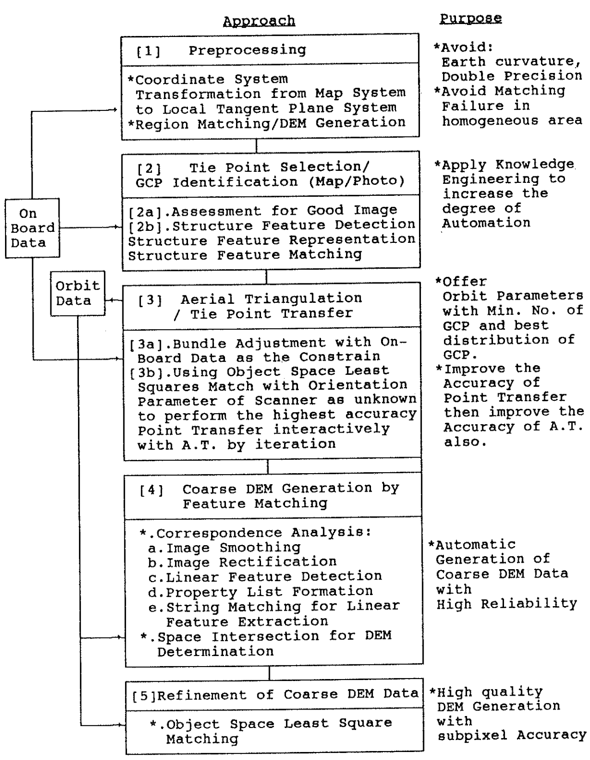
(c) Matching Strategy:

* One way Search / Compare and Select from Target Window to Search Window
*** Two ways (mutually) Search / Compare and Select between each other
*** Solve / Determine the Unknowns
* Multi-Pixel Matching ---> one point determination
*** Multi-Pixel Matching---> Multi-points determination (Weighting the good / high contrast pixels to help the poor pixels result in higher Reliability)

(d) The Minimum Cost Sequence of Error Transformation:

* City Block Distance (Min. Absolute Difference)
*** The Min. Euclidean Distance in Euclidean Space(Isotropic) (The Weighted Min. Distance in Feature Space)
*** The Least Squares Adjustment(Σvv --> Min.) with unequal weight

4.2 Summary of the process stages and their purposes



5. CONCLUDING REMARKS

In general, computer stereo vision belongs to the class of Ill-Posed inverse problem. Although the Object Space Least Squares Matching is the most rigorous method with high precision from a theoretical viewpoint, but it is a serious Ill-Posed Problem, and is difficult to implement in practice, therefore, every method to improve the computational stability of image matching is very important, e.g. try to include all available geometrical constrains, such as the regularization method to minimize the surface curvature is tried to help the convergency of solution; the idea of pyramidal approach is used to improve the problem that the range of convergency is very small, etc..

On-Line system for automatic DEM generation can be used in the map production line because an operator is still involved. It means that all the matching algorithms still can not completely solve all problems because the images of terrain and the terrain itself are so complicated. However, when matching has failed, a well trained operator who has sufficient knowledge about problem solving of stereo compilation of mapping can intervene. Therefore, if we can establish a Knowledge Base in which there is knowledge such as the well trained operator has, and incorporate it into the off-line system as an Expert system, we may obtain a similar capability as the on-line system with an operator. Hereby, we need to implement our approach to the computer in a semi-automatic / interactive mode with human interference in order to gain more experience and enough knowledge to enter into a Knowledge Base; then the problems of automatic DEM generation can be solved by an Expert System with sufficient knowledge in its Knowledge Base. Some primary experiments have been done for system start up/ interior orientation/ relative orientation in the measurement stage to perform diagnostics during the process [Kretsch, 1988]; there is still a long way to go for handling the whole system by a mature Expert System. Therefore, we have to start implementing our approach in the computer to accumulate our knowledge and improve the Expert System.

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