Feature Based Photogrammetry

Jussi Heikkinen

Helsinki University of Technology
Institute of Photogrammetry and Remote Sensing
P.O. Box 1200, FIN-02015 HUT

Jussi.Heikkinen@hut.fi

1 Introduction

Photogrammetric measurements have been based on pointwise measuring procedure for many decades. Partly it has been because of tradition in photogrammetry and partly because of limitations of measuring devices. Pointwise measuring requires that measured image point on one image has to be identified on another image or images corresponding the same 3D object point. The mathematical formula for expressing this dependence is based on collinearity, or case of stereo, on coplanarity condition. In analog stereomapping devices the conditions were established in mechanical way. In analytical stereodevices on the contrary the effect of condition is computed and based on this calculation the viewing condition is adjusted so that the measuring point and images on left and right eye fulfill the condition in all time. Even with digital plotters the measuring algorithms are handled in a similar way as with analog and analytical counterparts. Measurements are done with stereo and the analog images are substituted with digital counterparts.

In many photogrammetric mapping software the measuring task only supports pointwise data collection. Even for the linear line type object features, data is collected point by point in stereo mode. The point topology is then added afterwards or measuring mode tells how the individual points are connected. The linear line can be stored in polyline segments or in more sophisticated procedure measurements are filtered by adjusting a parametric line or curve into 3D point set. With digital plotters measurements mainly follow the same pattern. Some automation although is involved in DTM generation and automatic triangulation. In both tasks this means seed point detection in one image and search process in order to find its counterpart on other image or images.

In feature based photogrammetry the measuring principle differs from pointwise method in a way that contrast to point wise method image points belonging to certain object feature are measured. So point to point correspondence is never required nor 2D feature to 2D feature correspondence. The only dependence is image point set correspondence from two or multiple images on object feature. How the image point measurements are collected, from analog or digital images, is not essential. Digital image supports only better the automatic or controlled image observation extraction.

We talk here about features and linear features. The word ”feature” has in digital image processing and pattern recognition different meanings. Here, the feature is understood as a three dimensional object which has an explicit parametric presentation. The linear features are then parametric lines or curves who have parametric presentation of their position in chosen co-ordinate system and shape parameters define their possible shape, size and orientation. So the linear feature is a set of three dimensional point set, which fulfill a certain path in 3D space. Such type of curves are lines, b-splines, circles, ellipses and other conic sections as parabola and hyperbola. This kind of curves can be generated from any 3D point sets collected in various ways. So 3D points can be collected point by point with point wise measuring approach. Only problem is that correspondent point on continuous curve is very difficult or even impossible to determine precisely. Especially, if curve has a very complicated shape i.e. b-spline and images are taken quite much apart from each other. In feature based photogrammetry the feature parameters, photogrammetric condition, collinearity or coplanarity, and image observations are handled in same adjustment. So no adjustment or curve fitting is done in image space. The whole adjustment is performed in object space.

The linear features can be used in all photogrammetric tasks, in space intersection, resection and triangulation. The use of linear features are especially applicable in mapping of constructed areas. Since man-made objects include lot of linear curves especially straight lines. Also natural objects like river bank lines and coast lines as well as vegetation boarders offer good possibility to apply feature based approach in mapping.

In order to successfully apply feature based measuring methods the choice of right feature model (line, b-spline,circle etc.) is crucial. If you choose a wrong model, you may be able to fit image observations on selected feature model, but you get unprecise presentation of object or it may lead to ambiguity in object reconstruction. In order to stabilize the adjustment procedure you can solve parameters of multiple features simultaneously including constraints between features. You can set constraints of perpendicularity, parallel lines, coplanar features etc. between selected object features. These constraints may improve your fitting process in case of noisy image observations or it may lead to wrong solution if your assumptions are not grounded. The constraints can be given a certain various weight in order to tune the restrictness of the condition.

As a thumb of rule, constraints improve the adjustment and increase the redundancy in estimation. Each constraint adds an additional parameter in adjustment and in case of multiple constraints, it may lead to over parameterization. This danger is especially with very complicated object reconstruction tasks. The solution to this problem is to apply isometry principle. In this technique the primary object models, as cube, cylinder etc., can be presented with their own parameters. The parameter set can be divided into external and internal parameters. External parameters express the position and orientation of object model respect to co-ordinate system. Internal parameter set presents the shape and size of the object model in local co-ordinate system. This type of presentation resembles the way how the object models are presented in CAD systems.

2 Background

Before this type of modeling had been introduced in photogrammetry, in computer vision community similar techniques had been investigated a while. Researchers in computer vision have predominantly concentrated on automation of object reconstruction. In 1988 Prof. Edward M. Mikhail and Dr. David Mulawa presented the concept of linear features in photogrammetric tasks (Mulawa and Mikhail 1988). In this paper they introduced the concept of linear feature and presented the formulation for photogrammetric observations and linear features to be combined in adjustment procedure. This was the first step to combine feature based methods with estimation theory. Later in 1989 Dr. Mulawa expanded the mathematical model in his Ph.D theses (Mulawa 1989) to include different sensor model and presented the principle of isometry with linear features.

Since that few research groups have been investigating the subject. In Finland research in this area was quite active in beginning of the 90'. Two master theses (Metsämäki 1991, Heikkinen 1992) were made, who especially dealt with the precision estimation of different formulations of specific features. The research from aspect of estimation theory was made by Inkilä and Heikkilä(Inkilä 1990, Heikkilä 1991). Heikkilä especially concentrated on robustness of estimation in his paper.

This preliminary work led to more application oriented research projects; one concentrating in robust estimation and detection of feature lines in a close range photogrammetric case. Another dealt with linear features in mapping application. The close range research projet was accomplished in MAPVISON system environment. The idea was to automatically extract lines on digitized video images and with help of robust estimation techniques to verify the correctness of object model. In this case a 3D line model. The investigation was accomplished by Anja Wilkin (Wilkin 1992) and the project was financed by European Community. The project lasted two years.

Another research project as well had duration of two years (92-94). This was a bit more application oriented and dealt with map revision with linear features. The idea was to use existing 3D line information to solve orientation of aerial photographs. The map update was also done by using techniques of feature based methods. This project aimed to speed up the map updating in constructed areas. As well as reducing the price of such a mapping process. This hypothetical saving was based on assumption, that by substituting the signalized ground points with 3D feature lines, we are able to drop off one phase, namely signalizing, in mapping process.

The problem in those days was that there was not 3D map data available. The GIS systems were all 2D or $2\frac{1}{2}$D. Meaning that polylines could be stored only in 2D but third co-ordinate could only be derived from DEM. That was not acceptable. So the 3D GIS had to be implemented in laboratory software. Today the things have changed and there exist several GIS systems offering this capability and surveying offices in municipal do support mapping in 3D.

The result of the research project was that linear features can be used in mapping process and precision of mapping based on feature lines are equal or sometimes even better than traditional mapping project. More detail description of this project is presented in separate report and articles at the end of this introduction (Heikkinen and Laiho 1992, Heikkinen and Laiho 1994, Heikkinen 1994). The project was financed by the National Technology Agency (TEKES) and persons involved with project were Jussi Heikkinen, Anita Laiho and Timo Alakoski.

The most of the research efforts are made to exploit the use of straight lines in photogrammetric measurements. The choice of line is natural cause it is easier to automate extraction of straight lines and projected 3D lines appear lines also in image space. Kurt Kubik from Brisbane, Australia, investigated the minimum requirements of line features to be used in absolute and relative orientation(Kubik 1992). In Sweden Zielinski concentrated on line feature in space intersection case (Zielinski 1993). His line feature was based on four parameter model. Also in Purdue University in U.S.A., Prof. Mikhail and his researcher have been continuing the research on topic. The experiments conducted there by Kanok Weerawong were aimed to reveal the usage of linear features in practice (Mikhail and Weerawong 1997),(Weerawong 1995).

A little bit different approach to utilize feature line was presented by Tommaselli, who has been developing an automatic exterior orientation procedure for aerial photographs based on feature lines (Tommaselli and Poz n.d.). The object lines are supposed to be known beforehand. His idea is to restrict the line extraction into small image windows. The size of the window is dependent on precision of initial values of exterior orientation. So the automatically selected 3D lines from database are projected on images, lines nearby are extracted and line fitting on image is performed in order to get joint straight lines. According to image line parameters the relational matching is accomplished to solve correspondence between 3D line features. This requires converting line projections into image space line parameters. With help of statistical testing the right correspondences are found and the unknown exterior orientation parameters are solved based on this relation.

For aerial triangulation, where point and line features are combined, a little bit similar approach is presented in Ohio University by Ayman Habib (Habib n.d.). The original parametric presentation of line describes the infinite line with no end limits. In Habib's research the presentation of the object line is based on two points along the line. This choice is quite natural cause these points are easily obtained from a GIS database and the control line segment is then explicitly defined. The object line relation to the image space is bimodal. In one image the corresponding points of 3D line points are image points presented by x- and y-coordinates but in other overlapping images the corresponding line is measured and presented by two polar co-ordinates (ρ, ϕ). The latter presentation defines an infinite line. The relation of lines with polar co-ordinates to object line is defined as coplanar condition and relation of xy-presentation of line points in first image is based on collinearity condition. So in this method also the points of the line are included in adjustment. The line relation resembles the way Tommaselli has used it in his research but the image line presentation differs from his model, though.

3 Other Model Based Approaches

Since linear feature based methods were first time introduced, other so-called model based or model driven measurement methods have been presented. In a simple form this means fitting a 3D surface into a 3D point set. This is a natural technique when measurements are accomplished with laser scan systems as it is quite difficult to measure precisely discontinuities from 3D range data.

These object oriented image measurement approaches depend highly on the object model selected for representing the reality object. In many research projects the model representation used for objects is based on Constructive Solid Geometry (CSG) presentation. This is a representation widely used in CAD systems. The benefit of CSG representation is that it is highly compact and you are able to combine them by boolean operations, namely union, intersections and difference. The CSG models consist of two type of parameters; shape parameters and pose parameters. The drawback of such presentation is that it does not consist elements found on images. The boundary representation on the contrary includes edges, faces and is closer to entities found on images. In most methods the solution has been to combine these representations into a hybrid model where the compactness and flexibility to combine primitives of CSG models and capability of boundary models to use for interaction are utilized.

Most model base measuring methods require some human interaction. The initial values of model pose and orientation defined by operator are performed by adapting one or two parameters in time. For combining the interaction to desired parameter values Lang and Förstner have introduced an association table for handling the task (Lang and Förstner 1996). Usually the interaction is restricted to one reference image and the change of z-parameter value directs the image observation extraction to correct image area on other images. This works quite well in case of aerial photography, but the situation is different when working with terrestrial or inner space photographs. In some methods the model has to be posed and oriented on image quite accurately by hand, but in some methods it is enough to define only few parameters. In method presented by Gülch the operator has to define only few parameters and point out one arbitrary point on the ground in the vicinity of object and automatic image matching algorithm handles the height determination and guides the image feature extraction operations on other images in correct area.

How the final position and orientation of the object are then found and what image entities are used in fitting, differs in alternative methods. In some methods the image features used in model fitting are image edgels and in some the image gradient values define the exact location and orientation of the model. With algorithms using image edgels for fitting the edge detection is done beforehand or the edge detection is performed in restricted image area guided by projected wire-frame model. In case of object oriented measuring approach the a prior information about the direction and length of edges can be used to optimize the performance of edge operator to find edges belonging to wire-frame model.

The model-based fitting using edge information presented by Lowe (Lowe 1991) suggests to minimize the non-linear error function on image domain. In this fitting model the perpendicular distance between projected model line and extracted edge point will be minimized. The correct model line to image edge correspondence is found by selecting the one who has the shortest perpendicular distance, which is dependent on approximate model position. The object orientation can be then solved with respect to one viewpoint. If there is no knowledge about the size of the object, the distance of the object from camera will be undefined. But performing the fitting operation on multiple images taken from different viewpoints simultaneously with known partial orientation, also the translation and size of the object can be resolved.

Another alternative is to use image gradient values for fitting the model on images. In previous approach using edge information, the correspondence was searched from image edge to perpendicular direction to find projected model line or curve. In this procedure the search or information collection on image is done from the location of projected model line. In a selected range perpendicular to projected line, the image gradient values are computed. The strategy is quite different here compared to edge based method where image information is collected first and then compared with model data. This strategy can lead to some ambiguity in fitting process when part of the line has been occluded or suffers from shadowing. Then image gradient values not caused by the object are also included on fitting leading to incorrect solution. This was realized by Fua (Fua 1996) in his investigations. This was partly solved by applying hidden line algorithm to avoid these pitfalls. This surely removes the problem with occlusion caused by structure of the model itself, but the occlusion caused by other objects and shadowing is still unresolved.

When fitting the model on images Vosselman and Veldhuis (Vosselman and Veldhuis 1999) follow the procedure of Lowe (Lowe 1991) with exception where Lowe uses edge information and minimization of error function, they use gradient values as weights in observation equations in least square system. In order to stabilize and speed up the convergence of fitting algorithm, Vosselman and Veldhuis compute the gradient values in a grid, whose columns are perpendicular to projected line. The spacing of grid nodes is greater than a pixel size in the beginning but it is reduced as well as the size of the buffer along the iteration. In research of Fua (Fua 1996) the fitting of an object model is done by using polygonal snake algorithm. In Vosselman's and Veldhuise's approach the distance to projected line in grid points is minimized weighted by gradient values, but in snake algorithm it is the energy function of the snake that is minimized. In practice this means simply integrating the gradient values along the arc. The original algorithm consists only the 2D case, but the snakes can be extended to 3D space by adding the third co-ordinate to vertices and applying the projection function. The 3D snake can be solved when the polygon is projected on multiple images and minimization is accomplished simultaneously on all images.

All these algorithms assume the object model is known and has to be adjusted in image observation data. So interpretation and initialization of model parameter values have to be done by the operator. Only in few approaches the initial values are got automatically based on image clues (Henricsson et al. 1996) or based on other sensor data like laser scanner and existing map(Haala et al. 1998).

4 Summary

The linear feature concept has been presented over a decade ago, but the research work is still going on. The real evidence of capability of this method has been proved with practical experiments. Some suggestions also have been presented to automate the photogrammetric tasks. Despite of wide research efforts the feature based methods have not yet found their way to commercial products. Also the other model driven measurement systems are only implemented in universities in-house developed software, although some spin-of-companies are commercializing some university made or partly developed software (Inpho [InJect], CyberCity [CC-Modeler])

References

Fua, P. (1996). Model-based optimization: Accurate and consistent site modeling, Vol. XXXI, Part B3, ISPRS, Austria, Vienna, pp. 222–233.

Haala, N., Brenner, C. and Anders, K.-H. (1998). 3d urban gis from laser altimeter and 2d map data, Vol. XXXII, 3/1, Columbus, Ohio, U.S.A., pp. 339–346.

Habib, A. F. (n.d.). Aerial triangulation using point and linear features, *Automatic Extraction of GIS Objects from Digital Imagenary*.

Heikkilä, J. (1991). The use of linear features in digital photogrammetry, *The Photogrammetric Journal of Finland* **12**(2): 40–56.

Heikkinen, J. (1992). Linear features in photogrammetry (in finnish).

Heikkinen, J. (1994). Linear feature based approach to map revision., *International Archive of Photogrammetry and Remote Sensing*, International Society of Photogrammetry and Remote Sensing Commission IV Symposium, Athens, Georgia, U.S.A., pp. 344–351.

Heikkinen, J. and Laiho, A. (1992). The use of linear features as reference datum in digital map revision, Vol. XXIX, Part B4, ISPRS, Washington D.C., U.S.A., pp. 500–506.

Heikkinen, J. and Laiho, A. (1994). Final report in the project "tekes: A new mapping process with linear features", *Technical report*, Institute of Photogrammetry and Remote Sensing, HUT.

Henricsson, O., Bignone, F., Willuhn, W., Ade, F., Kübler, O., Baltsavias, E., Mason, S. and Grün, A. (1996). Project amobe: Strategies, current status and future work, Vol. XXXI, Part B3, ISPRS, Vienna, Austria, pp. 321–330.

Inkilä, K. (1990). Approximation by parametric spline curves, *The Photogrammetric Journal of Finland*, **12**(1): 69–81.

Kubik, K. (1992). Photogrammetric restitution based on linear features, Vol. XXIX, Part B3, Washington D.C., U.S.A., pp. 687–690.

Lang, F. and Förstner, W. (1996). 3d-city modeling with a digital one-eye stereo system, Vol. XXXI, Part B3, ISPRS, Vienna, Austria, pp. 415–420.

Lowe, F. G. (1991). Fitting parameterized three-dimensional models to images, *IEEE Transactions of Pattern Analysis and Machine Intelligence* **13**(5): 441–450.

Metsämäki, S. (1991). Fundamentals of feature based photogrammetry (in finnish).

Mikhail, E. M. and Weerawong, K. (1997). Expoitation of linear features in surveying and photogrammetry, *Journal of Surveying Engineering*.

Mulawa, D. C. (1989). *Estimation and photogrammetric treatment of linear features*, PhD thesis, Purdue.

Mulawa, D. C. and Mikhail, E. M. (1988). Photogrammetric treatment of linear features, *International Archive of Photogrammetry and Remote Sensing*, International Society of Photogrammetry and Remote Sensing, Kyoto, Japan.

Tommaselli, A. M. G. and Poz, A. P. D. (n.d.). Line based orientation of aerial images, *Automatic Extraction of GIS Objects from Digital Imagenary*.

Vosselman, G. and Veldhuis, H. (1999). Mapping by dragging and fitting of wire-frame models, *Photogrammetric Engineering and Remote Sensing* **65**(7): 769–776.

Weerawong, K. (1995). *Explotation of Linear Features for Object Reconstrution in Digital Photogrammetric Systems*, PhD thesis, Purdue University.

Wilkin, A. (1992). Robust 3d-object representation by linear feature, Vol. XXIX, Part B5, ISPRS, Washington D.C., U.S.A., pp. 659–666.

Zielinski, H. (1993). *Object Reconstruction with Digital Line Photogrammetry*, PhD thesis, Royal Institute of Technology, Stockholm, Sweden.