USE OF LINE SEGMENTS IN HIGH RESOLUTION SATELLITE IMAGE REGISTRATION

J.Heikkinen, A.Laiho-Heikkinen, H.Haggrén

Helsinki University of Technology, Department of Surveying Sciences,
Group of Photogrammetry and Remote Sensing
FINLAND
- Jussi.Heikkinen@tkk.fi
Anita.Laiho - Heikkinen@tkk.fi
Henrik.Haggren@tkk.fi

Commission VII, WG VII/6

KEY WORDS: Remote Sensing, Adjustment, Registration, Data Fusion, Georeferencing, High Resolution, QuickBird

ABSTRACT:

In recent years the research activity in image registration has grown at the same pace as the high resolution satellite images have found their way to end users. Much of this research activity has concentrated on methods improving the accuracy of georeferencing provided as RPC values. In this study the image registration via projective transformation based on straight line segments is investigated. The transformation parameters are solved based on real data extracted from topographic database and measurements done on QuickBird image. Same data is processed also with point wise method and accuracy numbers in selected check points are calculated. The RMS values computed in same check points prove that with the line based method the equivalent accuracy can be achieved as with the point wise method computed with minimum number of observations. In a smaller sub image the accuracy of transformation with line segments could be verified to be in size of a pixel.

1. INTRODUCTION

Georeferencing is an essential part of the process when combining satellite images acquired in different epochs or with different sensors. If data fusion is needed for image interpretation, classification, or change detection, precision of image registration has to fulfil task specific requirements. In point-wise method georeferencing can easily be accomplished within precision of one pixel. However, this precision usually requires manual work in selecting good points and satisfying proper point distribution. This is tolerable if the number of images to process is reasonable, but in case the data processing is regular and rather frequent, some automation for image registration is needed. Taking care of point distribution is a fairly straight forward task, but to recognize correspondences automatically is a demanding task. At the moment, most of the implementations of automatic image registration do rely on point-wise observations and area-based matching strategies. In a simple case they do succeed reasonably well, but in a more complex case they tend to suffer from some drawbacks. Most problematic in determination of correspondences is to deal with differences of varying radiances of an object point in case of images from different epochs. Also, when using point-wise methods and area-based matching strategies, discrepancies of occlusion patterns and casting shadows due to varying sensor orientations and time of acquisition affect results. By using feature-based matching approach there are better chances to detect these pitfalls automatically.

Feature-based matching algorithms exploit the power of interest-operators in order to extract large number of feature-point observations on cost of accuracy of an individual measurement. However, there is an option to extract feature-lines instead of feature-points. The fact that straight lines project as straight line segments on images speaks up for using these straight line segments in image registration. While searching correspondences multiple matching clues connected with line-features do enhance and encourage to exploit automation in image registration.

Full strength of line-based methods can be exploited if there are line segments on images which are substantially long compared to image dimensions. Unfortunately, this requirement is rarely fully met with satellite images. This drawback has been avoided in investigation of Barakat (Barakat et.all.,2004) by measuring few fairly good control points on images and constructing fictive lines between those measured points. The selected points were considerable long distance apart from each other constructing a solid base for line-based projective transformation. This way it was possible to solve transformation with fewer points than what would have been required to achieve the same accuracy in estimation with equations based only on point observations.

However, line segments to be detected on high resolution satellite images are long enough to be used alone in solving the image registration. Earlier, line-based methods have successfully been used with aerial images for map revision processes in order to solve sensor orientation and reconstruct of object features. The stability of line-features have been found robust and feasible in such tasks (Mikhail&Mulawa,1988), (Mulawa,1989),(Heikkinen,1994), (Mikhail&Weerawong,1994), (Habib,1999).

In this paper it will be shown that image registration can be accomplished within precision of few pixels using purely line segments found on a QuickBird image of a rural area. Object structures consisting straight line segments can be found in roof structures, straight road segments and bridges as well as boarder lines of field. Typically urban area offers a rich variety of such line structures, but also in rural areas there usually exist plenty of line segments to be detected and sometimes fairly long as well. It has to be remembered that uniform orientation of object lines does not provide enough information to solve the projection differences of images. Fortunately, there are no difficulties to find line segments with varying orientation in urban areas. Instead, in rural areas the variety of straight line segments is naturally more modest. But field borders are often straight and fairly long and also country roads frequently consist of fairly long straight lines. In this sense, use of lines for image registration is not restricted only to urban areas.

The image registration algorithm used in this research is based on eight parameter projective transformation between 2D parametric line equations. This approach has been earlier used by (Weerawong,1995), (Barakat et.al.,2004) also good presentation of used method can be found in (Mikhail et.all.,2001). Long line segments are preferable in order to determine 2D line parameters reliably since line parameters are the only observations in determination of the projective transformation. In real world case, it was found that line segments shorter than 30 pixels long should not be used. In determination of 2D line parameters and projective transformation LSQ estimation model was used.

2. USED METHOD

In aerial photography linear features and especially feature line segments have been used to solve exterior orientation of a sensor as well as intersect new object lines from two or multiple images. In formulation the image observations, projection center and object line parameters have been tied together in order to solve unknown sensor orientation. However, this requires some information about the imaging device, especially the focal length and lens distortion values. Unfortunately, this information is not available in case of satellite images. Therefore it is sensible to apply line based transformation in 2D. In this study line parameters are used as observations in order to solve the projective transformation between two data sets. The 2D projective transformation is a rectification between two planes imaged through perspective projection. This is only partly true with satellite images like QuickBird imagery. In row wise this requirement stands, but in column wise the imaging is closer to orthographic projection and in case of QuickBird the motion compensation even more violates this requirement. Even though this deficiency has not been considered to be crucial.

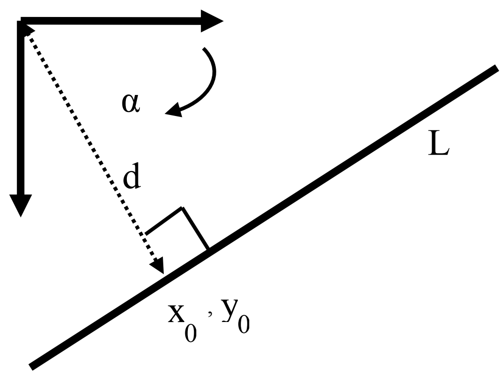

Figure 1 Presentation of parametric straight line

First, in calculation of projective transformation based on lines one must construct a parametric presentation of a line. This must be done for both data sets. The parametric presentation of line binds all the points (image or geographic points) belonging to this particular line.

There are at least two sets of parameters that can be used to represent line in 2D space. One is based on angle **α** and distance **d** from origin, see equation 1.

$$L = x * \cos\alpha + y * \sin\alpha - d = 0$$

(1)

The same line can be expressed with coefficients **a** and **b** in normalized line equation, see equation 2.

$$L = ax + by + 1$$

(2)

We can get from equation 1 to 2 easily by applying equation 3.

$$\begin{cases} a = -\cos\alpha / d \\ b = -\sin\alpha / d \end{cases}$$

(3)

It has to be noticed that both equations are ambiquous in case the line goes through the origin. In order to avoid such a case origin has to be shifted in computation of line parameters.

The point based projective transformation has eight parameters and minimum number of point observation is four (4) points not all lying on the same line, see equation 4. Similar equation can be constructed between line parameters derived from two different data sets, see equation 5. However, the parameters derived from line coefficients are not the same as parameters derived from point observations.

$$x' = \frac{e_1 x + f_1 y + g_1}{e_0 x + f_0 y + 1}$$
$$y' = \frac{e_2 x + f_2 y + g_2}{e_0 x + f_0 y + 1}$$

(4)

$$a' = \frac{r_1 a + s_1 b + t_1}{r_0 a + s_0 b + 1}$$
$$b' = \frac{r_2 a + s_2 b + t_2}{r_0 a + s_0 b + 1}$$

(5)

where x, y = map coordinates
x' , y' = image coordinates
e_0, f_0, e_1, f_1, g_1, e_2, f_2, g_2 = point based projective transformation parameters
r_0, s_0, r_1, s_1, t_1, r_2, s_2, t_2 = line based projective transformation parameters
a, b = line parameters in ground coordinate system
a',b' = line parameters in pixel coordinate system

The projective transformation presented in equation 5 uses line coefficients of equation 2. There exists an equation applying the line equation 1 and the same projective parameter set as with point based transformation, presented in (Weerawong,1995), see equation 6.

$$\begin{aligned} & d' * \left[e_1 * \cos\alpha' * \cos\alpha'' + f_1 * \sin\alpha' * \cos\alpha'' \right. \\ & + e_2 * \cos\alpha' * \sin\alpha'' + f_2 * \sin\alpha' * \sin\alpha'' \\ & \left. - d'' * (e_0 * \cos\alpha' + f_0 * \sin\alpha'') \right] \\ & + g_1 * \cos\alpha'' + g_2 * \sin\alpha'' - d'' = 0 \end{aligned}$$

$$\begin{aligned} & e_1 * \sin\alpha' * \cos\alpha'' - f_1 * \cos\alpha' * \cos\alpha'' \\ & + e_2 * \sin\alpha' * \sin\alpha'' - f_2 * \cos\alpha' * \sin\alpha'' \\ & - d'' * (e_0 * \sin\alpha' - f_0 * \cos\alpha') = 0 \end{aligned} \quad (6)$$

However, in our implementations the equation 6 was numerically too unstable with our data set and we could not get estimation to converge. On the other hand, the implementation of line parameters based on equation 2 and transformation based on equation 5 was successful and was the one used in this experiment.

3. DATA SET AND TEST ARRANGEMENT

The implemented estimation model was tested with QuickBird image acquired in spring 2006 in area of Vierumäki locating in southern part of Finland. The image was full image covering 16.5km×16.5km area and landscape was was typical agricultural area including two small residential areas. The image consisted only multispectral channels and was preprocessed on the standard level resulting an upscaled image with 1.66m pixel size.

As ground data topographic database from National Land Survey of Finland was used. From digital vector database road lines were selected as target vectors. The data was delivered as ESRI shape files. In database only centre line of the road was recorded. In order to filter out suitable straight lines from polyline spaghetti an own algorithm was programmed in EASI script language of PCI Geomatica software package. For the control lines only straight line segments longer than 100m were accepted. In filtering process all lines were examined taking care of straight line segment which extended over road junctions. In direction of successive line vector only 2.5 deg difference was allowed.

Correspondent line features were digitized from image manually. An alternative way would have been to apply some algorithm dedicated to road extraction, but since there was not such an algorithm available in software package and the primary goal in this investigation was to study accuracy of transformation with straight lines, the manual approach was considered to be adequate.

Altogether 30 lines were selected and measured from image. In addition 20 check points were measured in junctions of road network. The points selected consisted a fairly even distribution on an image. From 20 check points four were used as ground points for the purpose of comparison of point wise and line based methods. The remaining 16 points were used in both data sets as check points for testing an accuracy of transformation. Image measurements could be observed within precision of pixel or half a pixel. For the part of the topographic database location accuracy of road network was reported to be 3m on average, with higher level road network the location accuracy was apparently better than this, but with forest truck roads worse. Unfortunately, also line segments from lower level road network had to be used especially in forested area in order to get a proper line segment constellation.

4. RESULTS AND ANALYSES

The pixel observations of road line segments were used in estimation of line parameters of image lines. The same procedure was applied for node points of polylines filtered out from road network. These line parameters were then treated as observations of projective transformation in LSQ adjustment according to equation 5. Respectively, four check point pairs were used in LSQ adjustment of point wise projective estimation according to equation 4. All estimation procedures were programmed as MATLAB code.

In computation of line based projective transformation some numerical instability was noticed. Therefore it was considered to be necessary to get both data sets centered before line parameter estimation in order to stabilize the computation. Similar approach has been earlier presented in (Heikkilä,1991). The final adjustment was also computed in this shifted coordinate frame. In projective line adjustment the inverse of posterior line parameter variances from line estimation were used as weights in LSQ adjustment. After solving line projective parameters the equivalent point based parameters were computed according to equation 7.

This parameter set was then used to calculate forward and backward projective transformation in check point pairs in order to verify the accuracy of transformation, see table 1. In order to compare point wise and line based transformation four ground points were used to compute point based projective transformation and equivalent accuracy assessment was performed in same 16 check points, see table 2.

$$G = \begin{bmatrix} r_1 & s_1 & t_1 \\ r_2 & s_2 & t_2 \\ r_0 & s_0 & 1 \end{bmatrix} \quad (7)$$

$$H' = G^{-1}$$

$$H = \frac{H'}{H'_{[3,3]}} = \begin{bmatrix} e_1 & f_1 & g_1 \\ e_2 & f_2 & g_2 \\ e_0 & f_0 & 1 \end{bmatrix}$$

Line based	pixels		meters	
	X	Y	X	Y
Mean	4.30	6.59	7.19	11.03
RMS	5.46	10.05	9.12	16.83
RMS	8.09		13.54	

Table 1. Projective transformation computed based on line segments. Image was upscaled to 1.66m pixel size.

Pnt based	pixels		meters	
	X	Y	X	Y
Mean	5.81	8.14	9.68	13.57
RMS	6.39	9.18	10.65	15.31
RMS	7.91		13.19	

Table 2. Projective transformation computed based on four (4) points. Image was upscaled to 1.66m pixel size.

The calculated mean coordinate differences and RMS values in selected 16 check points show that the accuracy of line based transformation parameters are equivalent with point based transformation. In point based transformation the selected ground points located in near corner areas of the satellite image to provide a good geometry for computation. So the comparison can be considered to be fair regarding to stability of computation. The size of the RMS values appear to be rather big 5-10 pixels, but one has to bear in mind that image was upscaled to 1.66m ground element size, the corresponding RMS values would have been 3-6 pixels respect to real ground element size.

The line based method is known to work well in cases were the length of the line respect to whole value range is long. Therefore a line based transformation was computed in sub image area in size of 1km×1km. In selected area there were five (5) feature lines and the length of the lines was from 200m to 600m. The same procedure was followed as previously to compute the projective transformation. The correspondent presentation of accuracy of transformation calculated in three check points are depicted in table 3. Equivalently converted to RMS values respect to real ground pixels, the corresponding values would be 0.3-2 pixels.

Sub area	pixels		meters	
	X	Y	X	Y
Mean	0.43	2.40	0.71	4.00
RMS	0.46	2.71	0.76	4.50
RMS	1.94		3.23	

Table 3. Line based projective transformation computed in bounded area. Image was upscaled to 1.66m pixel size.

The results show that lines suit well for rectification of a smaller image area without any point observations. In all cases RMS Y values are six times larger than RMS X values on average. This tells something about the nature of QuickBird imaging. In row direction (X-axis) the assumption of perspective projection is valid which is not true in column direction. Also, it is assumed that the area is rather flat, In area under inspection the average fluctuation in height was around 30m and maximum difference was 60m.

5. CONCLUSION

Line based projective transformation was tested in manually selected image points and RMS values in those points were 3-6 pixels. The results were equivalent with point based method with four well selected tie points. The test was accomplished with QuickBird imagery consisting multispectral channels. The experiment does show that it is possible to compute projective transformation based only on line segment information with real data. This computation was conducted with multispectral channel having a ground element size 2.44m-2.88m. More potential results could have been expected if the same test would have been applied to the panchromatic channel. However, the same procedure applied in smaller sub-image area resulted a RMS value near to one pixel. The lines do provide good opportunity to apply automation by means of feature matching and is therefore worth of investigation.

REFERENCES

Barakat, H., Emam, H., Abdel-Wahab, M.,2004. Assesment of a Developed Combined Point/Line-based Projective Equations. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Istanbul, Turkey, Vol. XXXV, Part B3, p. (6)

Habib, A.,1999, Aereal triangulation using point and linear features. In: The *International Archives of Photogrammetry and Remote sensing,* XXXII (Part 3-2W5), pp.137-141

Heikkinen, J.,1994. Linear feature based approach to map revision. In: *The International Archives of the Photogrammetry, Remote Sensing,* Athens, Georgia, U.S.A. Vol. XXX, Part 4, pp. 344-351

Heikkilä, J.,1991. Use of Linear Features in Digital Photogrammetry. *The Phtotogrammetric Journal of Finland,* vol 12, num 2, pp. 40-56.

Mikhail, E., Bethel, J., McGlone, J.,2001. *Introduction to Modern Photogrammetry,* Chapter 4 *"Mathematical Concept in Photogrammetry".* John Wiley&Sons,2001, pp. 80-106.

Mikhail, E., Weerawong, K.,1994, Feature-based photogrammetric object construction. *In Proceedings of ASPRS Annual Convention,* Reno, Nevada, U.S.A.

Mulawa, D.,1989, *Estimation and Photogrammetric Treatment of Linear Features.* PhD thesis, Purdue University, p. (312)

Mulawa, D., Mikhail, E.,1988. Photogrammetric treatment of linear features. In: *The International Archives of the*

Photogrammetry, Remote Sensing, Kyoto, Japan, Vol. X, Part B3, pp. 383-393

Weerawong, K.,1995. *Exploitation of Linear Features for Object Reconstruction in Digital Photogrammetric Systems.* Dissertation, Purdue University, p. (192)

ACKNOWLEDGEMENTS

This study has its background on a co-operation project between Finnish Geodetic Institute and Helsinki University of Technology. We wish to thank Prof. Juha Hyyppä for his co-operation.