Image Subpixel Estimation by Evaluation of *ON* Satellite Sensor Model

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Abstract — *M*is-registration of ground control points caused by mixed pixels are the most significant error sources in remote sensing. Even though the effects of these errors on land-cover application have been so far widely investigated, no sufficient attention has been given to their impacts on satellite sensor geometry. In this paper the effect of such errors on sensor model accuracy and the possibility of using orbital *epipolarity* constrains of Orun & Natarajan (*ON*) satellite sensor model to avoid such errors are investigated.

INTRODUCTION

This paper addresses the issues of combination including image resolution enhancement, mixed pixel and the mis-location / registration of ground control points (GCPs) on satellite images. The resolution enhancement techniques of the satellite images have been in increasing demand in the last few years especially in the area of land cover or feature detection. The image resolution enhancement may be possible by separating the classes in the mixed pixel area. In land cover studies especially mixed pixels are the major problems and largely studied by Czaplewski [1], Fuller et al.[2], Stehman [3] and Muller et al. [4]. Foody [5] indicates that land cover and its dynamics are the potential sources of environmental information. He also investigates the role of soft classification techniques in mixed pixels in the estimates of GCP location. As it is known the mixed pixels can not be represented in conventional digital form and this limitation leads to a mis-registration of the location of GCPs. Hence it is a major problem in mapping and land cover monitoring. In this work the emphasis for resolution enhancement is only made on restricted local area where GCPs exist but not on whole imagery.

The mis-registration of GCPs is crucial and has far more greater impact on satellite epipolar geometry than the other remote sensing applications such as land cover identification. Since the GCPs are selected amongst the precise ground features such as road junction, coastline, river, etc. which are visible on both satellite stereo image pair, their selection and characteristics are big issues and so far investigated by several authors [6][7][8]. Mixed pixels in most cases are produced by coarsening of spatial resolution of satellite image [9][10] and has a direct effect on mis-location of GCPs. These errors cause unstability of sensor model and consequently lead to miscalculation of ground points' co-ordinates.

In this work the effect of mixed pixels on *ON* satellite sensor model and the possibility of utilising *ON* sensor model to bring a solution to the mixed pixel problem is investigated. The *ON* sensor model has been developed with the modification of well known photogrammetric bundle adjustment method and used for various satellite imagery such as IKONOS, KOMPSAT and SPOT. In general the accuracy of satellite sensor models has been restricted to several factors such as image co-ordinate measurements of the ground points (especially GCPs), no matter whether these measurements are done manually by using photogrammetric instruments or by fully automated image matching techniques [13]. The other factor is an adequate distribution of GCPs on the test field [12].

ON SATELLITE SENSOR MODEL

ON satellite sensor model has been developed [12] with some modifications made on the well known conventional photogrammetrical bundle adjustment technique [11]. In the model each horizontal line of the satellite image, which corresponds to the satellite linear sensor array, is treated like a single aerial photograph. But the fundamental difference is that image co-ordinate x has no dimension and should be set to zero. In the collinearity equations 1 and 2, X_s,Y_s,Z_s are the co-ordinates of satellite location and X_i,Y_i,Z_i are co-ordinates of a single ground point (e.g. GCP). f_i denotes the principal distance (focal length) of the sensor. The collinearity equations for a single linear array would be denoted as

$$0 = -f_1 \frac{r_{11}(X_i - X_s) + r_{21}(Y_i - Y_s) + r_{31}(Z_i - Z_s)}{r_{13}(X_i - X_s) + r_{23}(Y_i - Y_s) + r_{33}(Z_i - Z_s)} \quad (1)$$

$$y_i = -f_2 \frac{r_{12}(X_i - X_s) + r_{22}(Y_i - Y_s) + r_{32}(Z_i - Z_s)}{r_{13}(X_i - X_s) + r_{23}(Y_i - Y_s) + r_{33}(Z_i - Z_s)} \quad (2)$$

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where r_{ij} are the elements of image rotation matrix R, which contains trigonometric functions of linear array tilts (ω_s, φ_s, κ_s). In linear array geometry, due to high correlation between ω_s and Y_s, and also between φ_s and X_s, it is necessary to eliminate either ω_s or Y_s and either φ_s or X_s in the equations 3.

$$
\begin{aligned}
X_s &= X_0 + a_1 t + b_1 t^2 \\
Y_s &= Y_0 + a_2 t + b_2 t^2 \\
Z_s &= Z_0 + a_3 t + b_3 t^2 \\
k_s &= k_0 + a_4 t + b_4 t^2 \\
&\begin{Bmatrix} \omega_s = \omega_0 + a_5 t + b_5 t^2 \\ \varphi_s = \varphi_0 + a_6 t + b_6 t^2 \end{Bmatrix}
\end{aligned}
\qquad (3)
$$

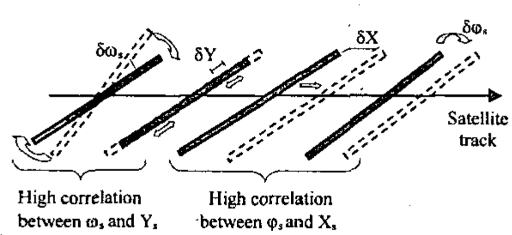

Figure 1. satellite sensor array geometric variations Caused by sensor array attitudes along the track

The epipolar geometry of *ON* sensor model may also be represented by equation 4 [14], where, (x_l, y_l) and (x_r, y_r) are the co-ordinates of left and right image points, $k_1 \sim k_9$ are constants and $Q(x_r)$ is a quadratic polynomial of x_r.

$$
y_r = \frac{k_1 x_l + k_2 y_l + k_3}{(k_4 x_l + k_5 y_l + k_6)\sin Q(x_r) + (k_7 x_l + k_8 y_l + k_9)\cos Q(x_r)} \qquad (4)
$$

Numerous experiments have been done on epipolarity using *ON* sensor model (e.g. Lee and Park) [15] and it has been indicated that the sensor model yields highly accurate results when ground control points and ephemeris data are provided.

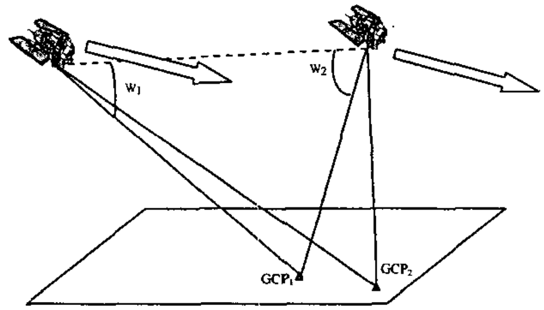

Figure 2 - Satellite epipolar geometry

THE TECHNIQUES USED

In this work the iterative bundle adjustment method [11] which was previously exploited in *ON* Satellite sensor model [12] which is based on satellite epipolar geometry is used to calculate the accurate sub-pixel locations of GCPs on satellite image by the use of conditional constrains in epipolar geometry. Within the software package the iteration continues until the maximum epipolar geometric accuracy is reached, this corresponds to the point where the geometric stability level is above the certain threshold. The flow diagram of operation is shown in Figure 3.

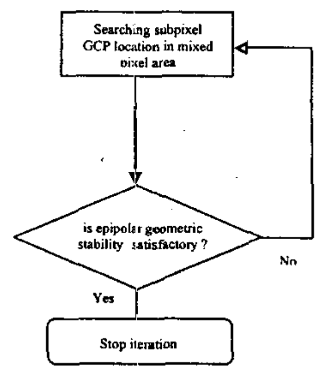

Figure 3 - Flow diagram of mixed pixel classification by epipolarity condition

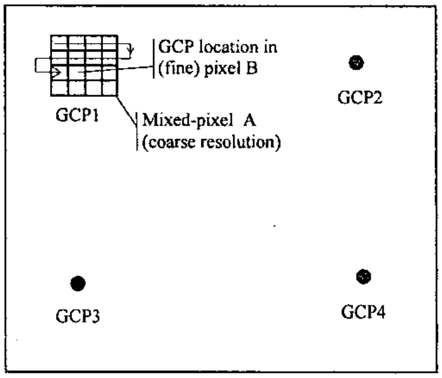

Figure 4 - Distribution of GCPs and searching the GCP1 sub-pixel location

In figure 4 the distribution of GCPs and searching procedure of GCP1's sub-pixel location in mixed-pixel area which is represented by pixel A of a low resolution image. Here (for presentation) the fine resolution image pixels (B) are superimposed on coarse resolution image pixel A. The fine image and its degraded form by averaging over a 5x5 pixel window area are shown in figure 5.

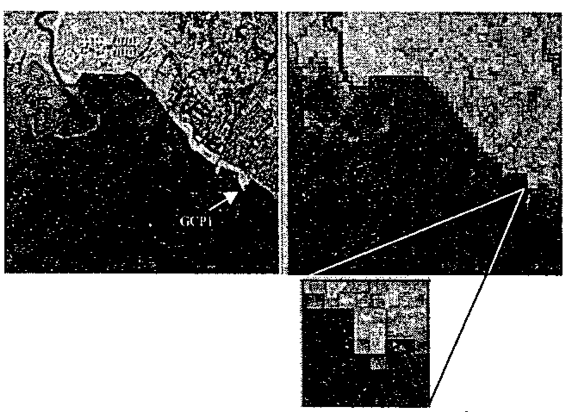

Figure 5 - Satellite image of a coastal area and its degradation by averaging over 5-by-5 pixel window area.

THE RESULTS

For testing the algorithms the simulated *ON* sensor model is used for an ideal conditions where satellite attitudes are assumed not to change unpredictably for both stereo pair on a limited track distance. This is inevitable for an adequate error analysis where all external error sources except those originated from mixed pixels are avoided. According to the results shown by the graphs in figure 6, any subpixel error contained by y image co-ordinate have larger effect on epipolar geometry (especially on Z co-ordinates of ground points) than it is contained by x image co-ordinates. Whereas any subpixel error brought to x image co-ordinate has almost equal effect on X and Y co-ordinates of ground points.

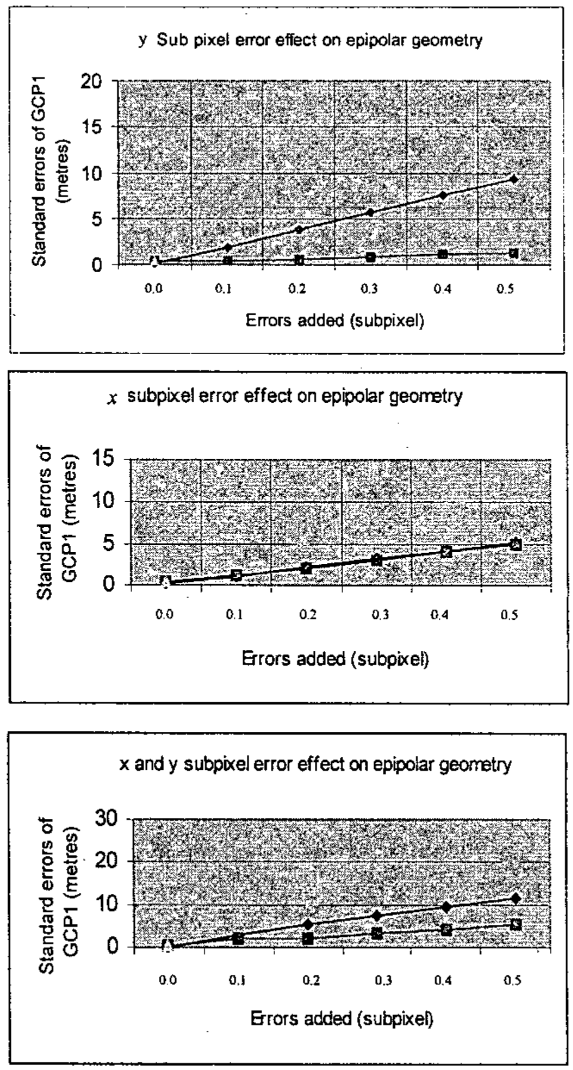

Figure 6 - The effects of x,y image co-ordinate subpixel errors on the epipolar geometry lines indicates the standard errors of GCP locations.
(*Yellow* = Z, *Magenta* = Y and *Blue* = X co-ordinates)

As it is shown in figure 6 in case of simultaneous error occurrence in x and y image co-ordinates, GCP elevation inaccuracy is maximized.

CONCLUSION

The analysis of mixed pixel errors and their effect on the satellite sensor models should be taken into account since they lead to inaccurate DEM (digital elevation model) generation. This inaccuracy reaches up to 20 metres when each x and y image co-ordinate contain 0.5 pixel error, and may be even higher in case of using narrower sensor viewing angle (w). Within this simulation Ws were kept as constant (15^0 and 25^0 for left and right images) to test the model in a certain epipolar condition. In the second part of tests, possibility of finding the correct location of GCP1 has been investigated. Since the correct subpixel location is found by comparing the results and selecting the best case among the others, and also because of using the certain (fixed) conditions of epipolar geometry, no any difficulty is experienced to reach the solution.

The further analysis in the future would be testing the model with different parameters (e.g. different W angles, attitude changes, more (simultaneous) GCP errors, etc.) and modelling all sorts of varieties and uncertainties by non-linear classifiers such as Bayesian networks would yield satisfactory results even in more complex epipolarity conditions.

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