RPC based Block Adjustment using KOMPSAT Stereo Images

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ABSTRACT: The three-dimensional (3-D) Geo-positioning from stereo images is one of the main applications for satellite images and is used for a variety of fields including national development, Geo-spatial information, and mapping. However, even if satellite images are acquired in a wide of areas or inaccessible area, it is difficult to obtain sufficient ground control points. In order to verify the 3-D positioning accuracy using a few Ground Control Points (GCP), in this study, the Rational Polynomial Coefficient (RPC) based block adjustment model is established from the stereo images and the RPC data. In addition, to calibrate the RPC data, which is with bias by geometric distortion of sensor, parameters are calculated by shift terms and affine model. In case shift terms only was applied respectively, the check points show 40 cm, 30 cm level of accuracy. If the affine model is used, less than 20 cm of accuracy could be obtained. Based on this result, it is expected that the positioning accuracy of sub-meter level by a few GCPs can be calculated.

1. INTRODUCTION

KOMPSAT-3(KOrea Multi-Purpose SATellite-3), KOMPSAT-3A launched in 2012, 2015 and provide users with high-resolution satellite images that are 55 cm, 70 cm of the panchromatic band. The high-resolution satellite images allow them to be used in a wide range of applications. It is possible for satellite image to complement the problems of the repeat cycle and swath width that have been pointed out as the disadvantage of aerial photography. In particular, it is widely used in the field of topographic model generation because the stereo images calculate the 3-D positioning and the satellite can take image without any constraints in any area of the Earth. Therefore, it is used as useful data for the production of topographic data, orthometric image in the area where it is impossible to access and cannot surveying. By using the location of camera sensor and ephemeris data, 3-D positioning can be determined from Rigorous Sensor Model (RSM). Recently, the RPC data from Rational Function Model (RFM), which causes the bias of the location accuracy, so various studies were performed in order to calibrate the bias of the RPC data(Fraser 2003, Grodecki 2003, Fraser 2005). Also, The practicality of block adjustment model was checked using IKONOS high-resolution satellite images and RPC data(Grodecki, 2003). It is difficult to obtain many GCP even if the satellite images are acquired in a wide range of areas or inaccessible area. In order to verify the 3-D positioning accuracy using a few GCP, in this study, the RPC block adjustment model is established from stereo images and the RPC data of KOMPSAT-3, 3A. Based on this result, the possibility of 3-D positioning is to be confirmed.

2. STUDY AREA AND MATERIAL

In this study, the reference data of the Mongolia Cal/Val site established by the KARI was used(Seo and Hong, 2015), and the geodetic coordinate and GNSS-derived orthometric height determined from the GNSS static surveying. Table 1, 2 shows the information of stereo images used in this study and the distribution of the geometric condition, overlap area, the GCPs and check points.

Table 1. The properties of the used KOMPSAT-3 and KOMPSAT-3A stereo data set

Satellite	Imaging date	Attitude (deg.)			GSD (meter)		Overlap (%)
KOMPSAT-3	2014.04.02	-22.417	-0.156	-2.358	0.852	0.767	91.872
KOMPSAT-3	2014.05.27	21.0343	-0.155	-2.293	0.841	0.777	
KOMPSAT-3A	2015.10.22	-6.080	-29.905	-0.822	0.643	0.750	95.617
KOMPSAT-3A	2015.10.22	-6.057	29.801	5.757	0.621	0.745	

To check the bias of RPC data provided with stereo images, the image-space coordinates were calculated by RFM, and the results are as shown in Table 3. The RPC bias was shown to have a constant direction and magnitude, and this paper was used shift terms (a_0, b_0) and affine parameter ($a_0, a_L, a_S, b_0, b_L, b_S$) for calibrating RPC data.

Table 2. The geometric condition, overlap area, and distribution GCPs and check points

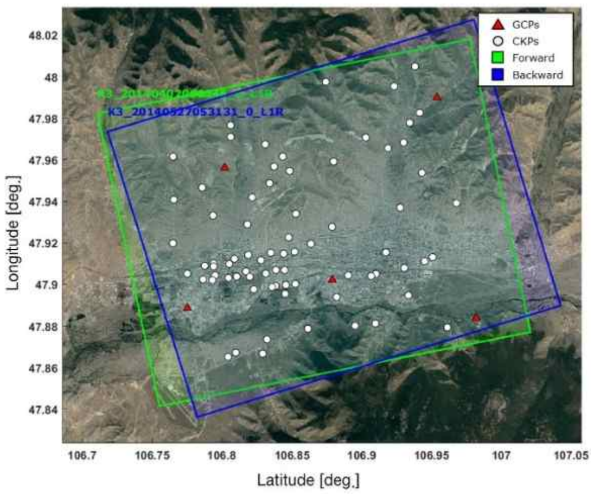
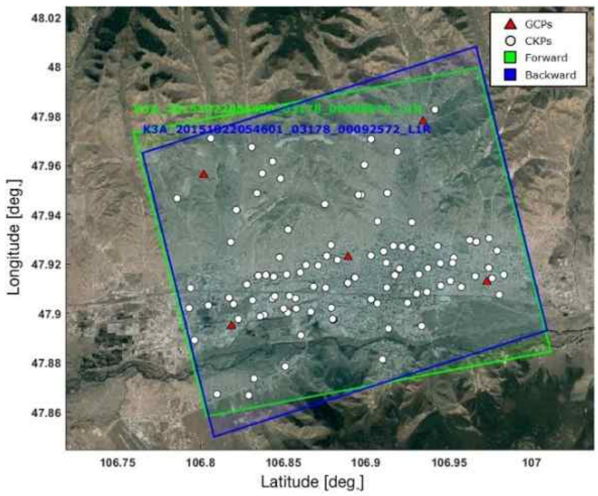
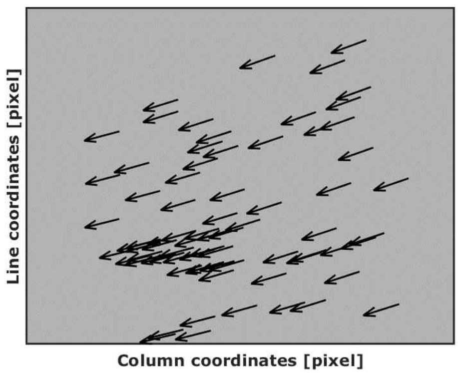
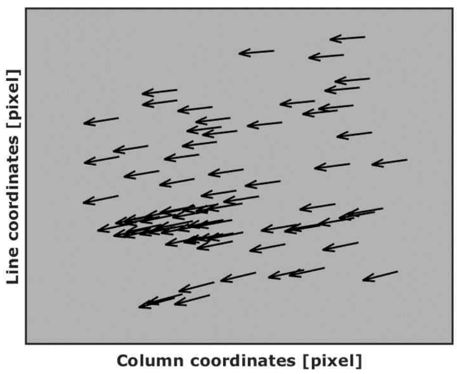
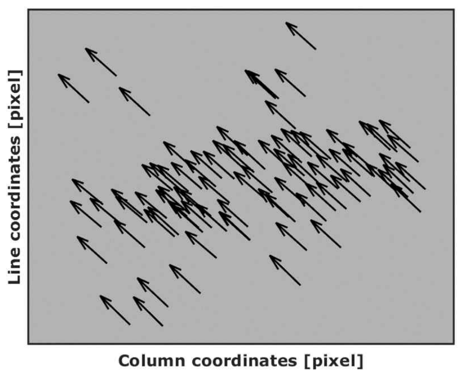
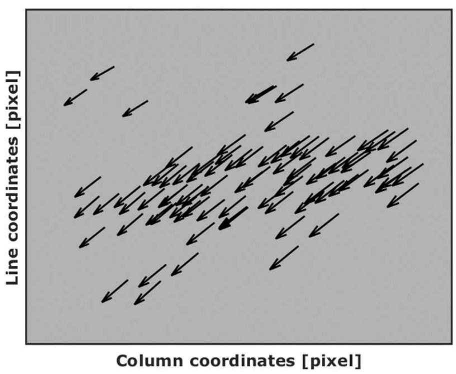
KOMPSAT-3 (Multi-pass)	KOMPSAT-3A (One-pass)
	

Table 3. RPC initial error in the image-space coordinates

unit : pixel

Images	Forward			Backward		
KOMPSAT-3						
Parameter	Range	Mean	STD	Range	Mean	STD
Sample	-37.241 ~ -35.741	-36.215	0.332	-34.241 ~ -33.074	-33.708	0.302
Line	-9.106 ~ -5.913	-7.367	0.853	-6.930 ~ -1.967	-4.429	1.201
KOMPSAT-3A						
Parameter	Range	Mean	STD	Range	Mean	STD
Sample	-16.549 ~ -15.541	-16.034	0.231	-11.711 ~ -8.389	-10.257	0.622
Line	8.060 ~ 9.571	8.731	0.275	-6.269 ~ -3.536	-5.487	0.434

3. METHODOLOGY

To establish the RPC block adjustment model proposed by Grodecki and Dial (2003), this paper use the stereo images and RPC data. To improve numerical precision, both object-space and image-space coordinates are normalized to -1 ~ +1 range. It can express between the image-space *i*th(*l, s*) and object-space coordinates *k*th(ϕ, λ, h) from the relational express like Eq. (1). There is location error in the RPC data, because the RPC data is generated from physical sensor model. To perform the RPC bias-correction, the 3-D positioning accuracy is calculated using shift terms and affine parameter. The application of the Taylor Series expansion to the RPC block adjustment observation Eq. (1) results in linearized matrix which is Eq. (2), (3) for image *j*th. The dx_A is the sub-vector of the corrections to the approximate image adjustment parameters for *j*th images, the dx_G is the sub-vector of the corrections to the approximate object-space coordinates for *k*th ground control points.

$$F_{L_{(i)}} = -\mathrm{LINE}_{(i)}^{(j)} + \frac{P_1^{(j)}(\phi_k,\lambda_k,h_k)}{P_2^{(j)}(\phi_k,\lambda_k,h_k)} - \Delta l^{(j)} - \epsilon_{L_{(i)}} = 0 \qquad \Delta l^{(j)} = a_0^{(j)} + a_L^{(j)}\overline{\mathrm{LINE}}_{(i)}^{(j)} + a_S^{(j)}\overline{\mathrm{SAMP}}_{(i)}^{(j)}$$

$$F_{S_{(i)}} = -\mathrm{SAMP}_{(i)}^{(j)} + \frac{P_3^{(j)}(\phi_k,\lambda_k,h_k)}{P_4^{(j)}(\phi_k,\lambda_k,h_k)} - \Delta s^{(j)} - \epsilon_{L_{(i)}} = 0 \qquad \Delta s^{(j)} = b_0^{(j)} + b_L^{(j)}\overline{\mathrm{LINE}}_{(i)}^{(j)} + b_S^{(j)}\overline{\mathrm{SAMP}}_{(i)}^{(j)} \tag{1}$$

$$\mathrm{A}_{A_{(i)}} dx_A = \begin{bmatrix} 0 \cdots 0 & \frac{\partial F_{L_{(i)}}}{\partial a_0^{(j)}} & \frac{\partial F_{L_{(i)}}}{\partial a_L^{(j)}} & \frac{\partial F_{L_{(i)}}}{\partial a_S^{(j)}} & 0 & 0 & 0 & 0 \cdots 0 \\ 0 \cdots 0 & 0 & 0 & 0 & \frac{\partial F_{S_{(i)}}}{\partial b_0^{(j)}} & \frac{\partial F_{S_{(i)}}}{\partial b_L^{(j)}} & \frac{\partial F_{S_{(i)}}}{\partial b_S^{(j)}} & 0 \cdots 0 \end{bmatrix} \left[\cdots da_0^{(j)} da_L^{(j)} da_S^{(j)} db_0^{(j)} db_L^{(j)} db_S^{(j)} \cdots\right]^{\mathrm{T}} \tag{2}$$

Consequently, the RPC block adjustment model result in following matrix and the least-squares solution needs to be iterated until convergence is achieved. Here, C_P is the a priori covariance matrix of image-space coordinates, C_A is the a priori covariance matrix of the image adjustment parameters, and C_G is the a priori covariance matrix of the object-space coordinates.

$$A_{G_{(i)}} dx_G = \begin{bmatrix} 0 \cdots 0 & \frac{\partial F_{L_{(i)}}}{\partial \phi_k} & \frac{\partial F_{L_{(i)}}}{\partial \lambda_k} & \frac{\partial F_{L_{(i)}}}{\partial h_k} & 0 \cdots 0 \\ 0 \cdots 0 & \frac{\partial F_{S_{(i)}}}{\partial \phi_k} & \frac{\partial F_{S_{(i)}}}{\partial \lambda_k} & \frac{\partial F_{S_{(i)}}}{\partial h_k} & 0 \cdots 0 \end{bmatrix} \begin{bmatrix} \vdots \\ d\phi_k \\ d\lambda_k \\ dh_k \\ \vdots \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} \mathrm{Y}_P \\ \mathrm{Y}_A \\ \mathrm{Y}_G \end{bmatrix} = \begin{bmatrix} \mathrm{A}_A & \mathrm{A}_G \\ I & 0 \\ 0 & I \end{bmatrix} \begin{bmatrix} dx_A \\ dx_G \end{bmatrix} - \begin{bmatrix} \epsilon_L \\ \epsilon_S \end{bmatrix}$$

$$\mathrm{Y} = \mathrm{A}\,\xi - \epsilon \tag{4}$$

$$\hat{\xi} = (A^{\mathrm{T}} C^{-1} A)^{-1} A^{\mathrm{T}} C^{-1} Y \qquad \mathrm{C} = \begin{bmatrix} \mathrm{C}_P & 0 & 0 \\ 0 & \mathrm{C}_A & 0 \\ 0 & 0 & \mathrm{C}_G \end{bmatrix}$$

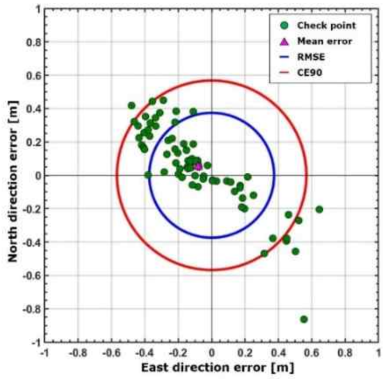
4. RESULTS AND DISCUSSION

According to the number of GCPs, the accuracies of the RPC block adjustment using shift model and KOMPSAT-3, KOMPSAT-3A stereo images are shown in Table 4, 5.

Table 4. Block adjustment results of the KOMPSAT-3 stereo images using shift model

unit : m

KOMPSAT-3 **(Num. of GCPs : 5 / Check Points : 74)**



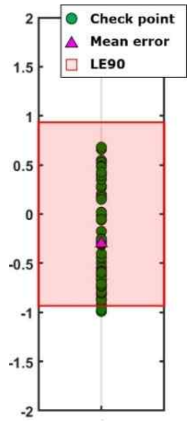
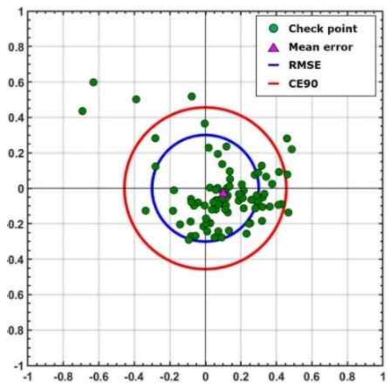


Image adjust parameter	Num. of GCPs	Error	Range	Mean	STD.	RMSE
Shift terms only (a_0, b_0)	1	dE	-0.424 ~ 0.704	-0.027	0.276	0.276
		dN	-0.694 ~ 0.662	0.221	0.238	0.324
		dU	-0.216 ~ 1.455	0.475	0.485	0.677
	3	dE	-0.511 ~ 0.614	-0.111	0.276	0.296
		dN	-0.744 ~ 0.569	0.169	0.237	0.290
		dU	-1.100 ~ 0.572	-0.408	0.486	0.632
	5	dE	-0.480 ~ -0.645	-0.081	0.276	0.286
		dN	-0.864 ~ 0.450	0.050	0.237	0.241
		dU	-0.991 ~ 0.681	-0.299	0.486	0.568

Table 5. Block adjustment results of the KOMPSAT-3A stereo images using shift model

unit : m

KOMPSAT-3A **(Num. of GCPs : 5 / Check Points : 89)**



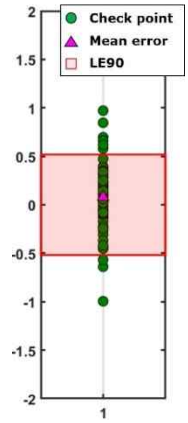


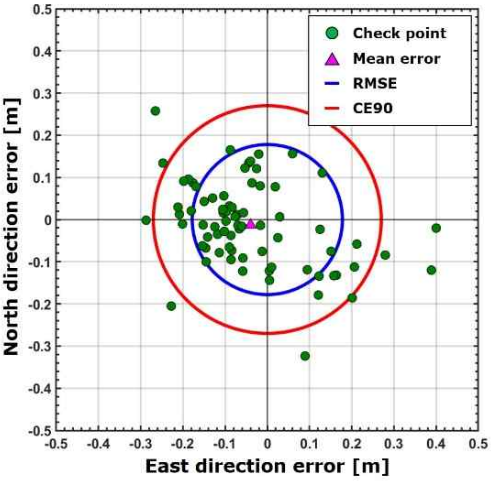
Image adjust parameter	Num. of GCPs	Error	Range	Mean	STD.	RMSE
Shift terms only (a_0, b_0)	1	dE	-0.754 ~ 0.422	0.038	0.217	0.219
		dN	-0.196 ~ 0.693	0.063	0.181	0.191
		dU	-0.840 ~ 1.127	0.236	0.307	0.386
	3	dE	-0.697 ~ 0.481	0.096	0.217	0.236
		dN	-0.294 ~ 0.595	-0.034	0.181	0.183
		dU	-0.951 ~ 1.016	0.142	0.307	0.330
	5	dE	-0.692 ~ 0.487	0.101	0.217	0.239
		dN	-0.291 ~ 0.598	-0.031	0.181	0.182
		dU	-0.995 ~ 0.972	0.080	0.307	0.315

Table 6, 7 show the block adjustment results of the KOMPSAT-3, KOMPSAT-3A stereo images using affine model.

Table 6. Block adjustment results of the KOMPSAT-3 stereo images using affine model

unit : m

KOMPSAT-3 **(Num. of GCPs : 5 / Check Points : 74)**



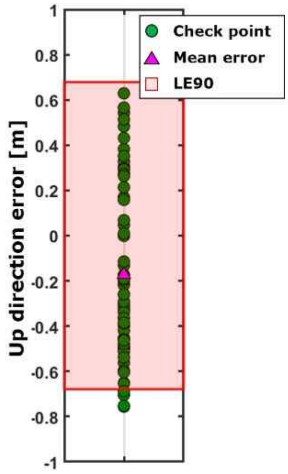
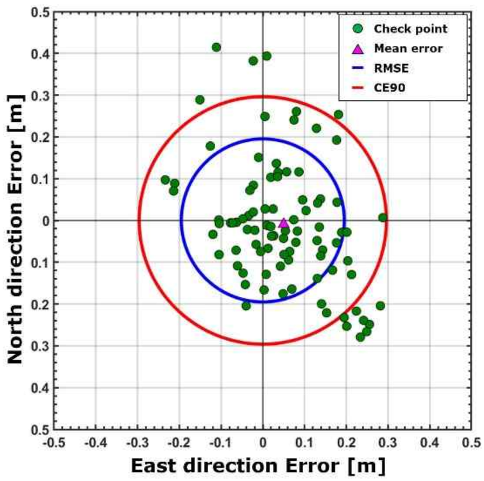


Image adjust parameter	Num. of GCPs	Error	Range	Mean	STD.	RMSE
Affine ($a_0, a_L, a_S,$ b_0, b_L, b_S)	3	dE	-0.514 ~ 0.743	-0.065	0.302	0.307
		dN	-0.282 ~ 0.259	-0.029	0.125	0.127
		dU	-0.402 ~ 1.908	0.126	0.441	0.456
	5	dE	-0.287 ~ 0.400	-0.040	0.142	0.146
		dN	-0.324 ~ 0.258	-0.013	0.101	0.101
		dU	-0.756 ~ 0.629	-0.173	0.377	0.413

Table 7. Block adjustment results of the KOMPSAT-3A stereo images using affine model

unit : m

KOMPSAT-3A **(Num. of GCPs : 5 / Check Points : 89)**



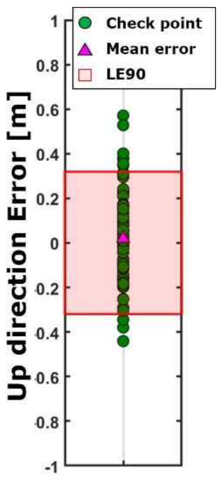


Image adjust parameter	Num. of GCPs	Error	Range	Mean	STD.	RMSE
Affine ($a_0, a_L, a_S,$ b_0, b_L, b_S)	3	dE	-0.653 ~ 0.394	0.034	0.203	0.205
		dN	-0.447 ~ 0.764	0.021	0.221	0.220
		dU	-1.290 ~ 1.694	0.143	0.518	0.534
	5	dE	-0.234 ~ 0.288	0.050	0.116	0.126
		dN	-0.279 ~ 0.415	-0.009	0.150	0.149
		dU	-0.441 ~ 0.571	0.019	0.194	0.194

5. CONCLUSION

As a result, when one GCP and shift model were used, the RPC block adjustment horizontal and vertical accuracy of the KOMPSAT-3 was 0.425 m, 0.677 m. In case five GCP were used, the accuracy of 0.374 m and 0.568 m was calculated, and the horizontal and vertical accuracy of the KOMPSAT-3A was about 0.300 m. If the affine model is used, the block adjustment accuracy of the KOMPSAT-3 and KOMPSAT-3A stereo image less than 0.200 m could be obtained. Based on the result, we expected that the location determination of the sub-meter accuracy by block adjustment model can be capable.

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