ACCURACY EVALUATION OF DIGITAL SURFACE MODEL USING ALOS PRISM DATA FOR DISASTER MONITORING

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ABSTRACT:

The need of accurate measurement is a tactical objective to produce precise information in disaster monitoring. A small movement of land could be a prior index to the biggest landslide. The biggest disasters can lead by a small unnoticeable changes. The measurement of 3 dimensional surfaces changes could be calculated accurately using very high resolution satellite stereo images. The availability of short-time periodic satellite's stereo-pair images are benefits to investigate the land movements when the images had acceptable accuracy. Vendors are providing camera replacement models with a set of rational polynomial coefficients (RPCs) to replace physical camera models for registration improvement. Fraser & Hanley (2003) represented that no loss in accuracy is to be expected when bias corrected RPCs are used for georeferencing. Even if RPC coefficients are provided by vendors, those are not enough to investigate small changes of land-form, slope displacements. Thus, we should be applied a pliant sensor model based on very accurate ground control points (GCP). First of all, high resolution digital surface model (DSM) is generated from ALOS PRISM triplet images; resulting X=0.97, Y=0.99 and Z=1.85 pixels in accuracy. This result was produced by stereo matching between nadir and backward looks. Finally, the accuracy evaluation of 3D measurement is conducted based on selected check points (CP). Afterall, error vectors will be produced by validating with Airborne Laser Scanner DSM data. Even though the result measurement will be biased with some errors, the future work could be improved by matching a series of triplet images.

1. INTRODUCTION

In disaster monitoring, accurate 3 dimensional surfaces measurement is a tactical objective to notice land movements and land-form changes. A small movement of land could be accumulated to form the biggest movement. Thus, the biggest disaster can be lead by a small unnoticeable land-forms change. The detection of the changes could be calculated accurately, when we used accurate input to the analysis process. Using very high resolution satellite images we could be detected small changes, if our input has potential in ground accuracy. Nowadays, there are a lot of very high resolution satellite images are available by the advancement of space satellites mounting optical sensors. Vendors are providing camera replacement models with a set of rational polynomial coefficients (RPCs) to replace physical camera models for registration improvement. Fraser & Hanley (2003) represented that no loss in accuracy is to be expected when bias corrected RPCs are used for georeferencing. Even if RPCs and alternative affine projected model are provided by vendors, some errors are still contaminating in the images. The errors could not cover for the sensor alignment. Ground control points (GCP) are necessary in geometric correction to precise (Hashimoto, 2006). In this study, we used GCP data acquired by GPS-VRS. It is a acronym of differential GPS based on Virtual Reference Stations.

First of all, it is need to generate high resolution digital surface model (DSM) from available satellite imagery. Using ALOS PRISM triplet data it could be possible to generate high resolution DSM data. In this study, we used triple image of ALSO PRISM to extract DSM. The image had such three looks as forward, nadir and backward; this conjugated triplet image could be input to generate DSM when the images are matched. The prior study found that ALOS PRISM data is contaminated with some systematic errors on along track of sensors. Those errors are accumulated in the forward and backward looks. The georeferencing result from vendors provided RPC model is 1.3 x 1.8 pixels accuracy in nadir, 7.11 x 1.8 for forward look and 8.4 x 0.9 for backward look. Based on result values, we found that more errors are in forward and backward and in along track direction. In this study, we corrected this contaminated systematic errors by applying 3D perspective projection. Elevated mountains, river low lands and farm plains are distributed on the selected study area. The situation of the study area is supporting to use 3D perspective projection for georeferencing. After applying the perspective projection model, the calculation produced accuracy improvement. Result values are in nadir 0.26 x 0.29 pixels, in forward look 0.26x0.27 pixels and in backward look 0.21 x 0.25 pixels respectively. The result of 3D perspective projection give better accuracy than vendor provided RPC models. Even if the accuracy of result is improved, the study agreed to provide very high accurate result. For the purpose, a corrected RPC model for triplet images was generated using ground control points (GCP). GCP are measured by GPS VRS observation to get very precise measurement. GPS VRS is a latest technology of location measurement; it is based on differential GPS with virtual reference station using wireless telecommunication. This measurement produced very high accurate location in collection of GCP. Then, stereo matching was conducted by least squares matching using available low resolution digital elevation model

(DEM). In this step we used 50 x 50 meters resolution DEM due to it is available freely. In order that, 3D coordinate calculation was done using triplet images of ALOS PRISM. It is possible to apply the calculation to other high resolution optical sensors mounting with pushbroom scanners such as SPOT 5 and Quickbird since ALOS PRISM sensor had same function with them. At last, the generated DSM is evaluated by validation points. In the registration process, 14 ground control points and 8 validation points were introduced; resulting X=0.97, Y=0.99 and Z=1.85 pixels in accuracy. This result was produced by stereo matching between nadir and backward looks. Even though the result measurement is bias with some errors, this result could be improved by triplet image matching and adding more validation points in future.

As of main a requirement, the study is investigated the potential of usage of ALOS-PRISM DSM in slope failure disaster monitoring with the area consistency of 10 square meters. As detectable region of interest, it is possible to detect greater than 5 square meters of the area because the spatial resolution of input image is 2.5 meters according to spatial resolution of ALOS PRISM sensor. Finally, changed detection result is evaluated. In the evaluation process, we created evaluation grids. Those grids are used to measure statistic values of the result image. Recently, this research work is applying to the land displacement monitoring project to prevent risky landslide disaster in the mountainous area. Future, we could be applied triangulated irregular network (TIN) model to time series DSM data sets together with evaluation grid statistic measurement.

2. SUDY AREA & DATA INFORMATION

2.1 Study Area

Study area is located on 4^{th} isle of the Japan. Geographically, it is a small portion of Kochi Prefecture of Shikoku Island and it had uneven elevated area. The area is one of the most landslide risk areas of Japan by proving many geological faults. Many landslides are happened in this area.

2.2 Data

There are two datasets are used in this study; a low resolution DSM data and ALOS-PRISM triplet data. The PRISM data is used to generate new DSM to measure land-form changes and land displacement. Some characteristic of ALOS-PRISM data is listed in the table 1.

Orbit	Sun-Synchronous Sub-Recurrent
	Repeat Cycle: 46 days Sub Cycle: 2 days
	Altitude: 691.65 km (at Equator)
	Inclination: 98.16°
Attitude Determination Accuracy	2.0 x 10^{-4}degree (with GCP)
Position Determination Accuracy	1m (off-line)
Data Rate	240Mbps (via Data Relay Technology Satellite) 120Mbps (Direct Transmission)
Number of Bands	1 (Panchromatic)
Wavelength	0.52 to 0.77 micrometers
Number of Optics	3 (Nadir; Forward; Backward)
Base-to-Height ratio	1.0 (between Forward & Backward)
Spatial Resolution	2.5m (at Nadir)
Swath Width	70km (Nadir only) / 35km (Triplet mode)
S/N	>70
MTF	>0.2
Number of Detectors	28000 / band (Swath Width 70km) 14000 / band (Swath Width 35km)

** PRISM cannot observe areas beyond 82 degrees south and north latitude.*

Table 1: Characteristic of ALOS-PRISM data

PRISM sensor is equipped with three optical independent systems to acquire digital surface model (DSM) with high spatial resolution. Three temperature stabilized radiometers of optical systems are pointing to forward, nadir and backward views. Thus, the sensor is set to generate 5 meters elevation data which is corresponded to the 1:25,000 scales in topographic map together with 2.5 meters spatial resolution. To maintain base-to-height ratio to 1, forward and backward radiometers are inclined ±23.8 degrees outwards from the nadir. To adjust the Earth rotation effect, each radiometer could use electrical pointing within ±1.2 (+1.5) degrees in cross-track. Thus, 35 km wide triplet images are acquired without yaw steering the satellite. Lossy compression with JPEG format is used to compress acquired data when it transmitted to ground station (Ohta, 2006). Pointing angle +1.5 degrees in cross-track is confirmed by PRISM first image observation (Tadono, 2006). The scanning geometry of PRISM sensor is shown in figure (1).

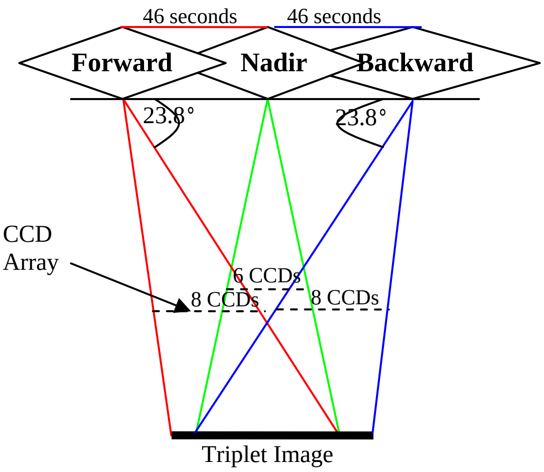

Figure 1: Scan geometry and triplet image of PRISM sensor

3. TRANSFORMATION MODELS

As the prior need of DSM generation, the selected stereo images pair must be ortho-rectified and corresponding pixels location should be geometrically corrected. Generally, RPC model is applied to stereo pair to generate ortho-rectified images and to correct pixels correspondence (Dowman, 2000; Tao, 2001). Consider producing high accurate ortho-images, remaining errors cannot adjust by the sensor alignment and GCPs are necessary for precise geometric correction (Fraser, 2005; Hashimoto, 2006). To produce very precise geometric corrected one, it is need to collect very accurate ground control points by GPS-VRS. The standard accuracy of GPS-VRS could be acquired below the centimetre level.

3.1 Ground Control Points

GPS-VRS is used to collect ground control points. The selection of GCP was carefully observed based on distinct features of ground to image such as road cross-sections and centre of bridges. Even 22 points are observed scattering in the whole image; 14 points are selected as GCP and other 8 points are defined as verification check points. All control points (GCP and CP) are located visually observation on the image.

3.2 Verification of Transformation Models

In general photogrammetry, a model defines a set of interior orientation parameters (Wolf, 1983; Mikhail et al., 2001). and exterior orientation parameters In this study, the transformation of ground objects (*x,y,z*) to image coordinates (*u,v*) could be done by 3D projective function using parameters of vendor provided replacement sensor model (RPC), when the physical sensor model is restricted to public. The coefficients of RPC model ca be variable based on the sensors. Without knowing the sensor information RPC coefficients are using in photogrammetric processing such as ortho-rectification, DSM generation without noticed accuracy loss (Grodecki, 2001). Firstly, vendor provided RPC model is observed. The residual errors of the model result are showed in the table 1. Then, the errors of RPC coefficients are verified by the coefficients of accurate GCP. As of transformation model, the 3D Projective function is used. The function some time called as direct linear transformation (DLT) model can be represented by equation 1.

$$u = \frac{(a_1x+a_2y+a_3z+a_4)}{(a_9x+a_{10}y+a_{11}z+1)}$$
$$v = \frac{(a_5x+a_6y+a_7z+a_8)}{(a_9x+a_{10}y+a_{11}z+1)} \quad (1)$$

where $a_1, a_2, \ldots, a_{11}$ are unknown linear orientation parameters between two dimension image space (*u,v*) and three dimensional objects space (*x,y,z*). The result of the model is showed in the table 2.

4. THREE DIMENSIONAL MEASUREMENT

The photogrametric model can be easily understood using simple below figure (2).

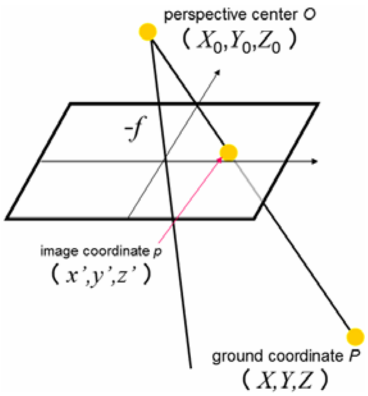

Figure 2: Simple photogrammetric model.

To extract 3D information from satellite images, at least two stereo images, interior geometry of the sensor and exterior orientation parameters is needed.

The study selected backward and nadir looks of ALOS-PRISM as stereo pair (figure 3). Moreover, the coefficient parameters are calculated with DLT model using GCP.

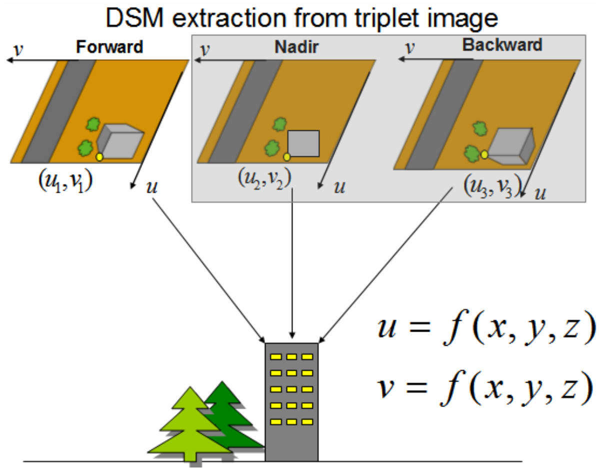

Figure 3: DSM extraction from PRISM data.

4.1 Stereo Image Matching

Fundamentally, satellite orbit and attitude information are used to generate DSM. Nadir-forward and nadir-backward pairs from triplet images are used to calculate parallax with tie-points by image-matching technique (Tadono, 2006). To generate tie-points automatically, least squares image matching is a powerful method to extract correspondence pixels from stereo pair (Gruen, 2005). In the method of least squares, the geometric differences can be modeled by affine transformation, while the radiometric differences are modeled by an additive and a multiplicative parameter. The main purpose of the method is to refine the approximate matching positions and to get high accuracy. The basic algorithm can be formulated in three dimensions with the following generalized equations:

$$g_t(x_t,y_t,z_t)+n(x_t,y_t,z_t)=g_s(x_s^0,dx,y_s^0+dy,z_s^0+dz) \quad (2)$$

$$\Delta g+n=\frac{dg_s}{dx}\partial x+\frac{dg_s}{dy}\partial y+\frac{dg_s}{dz}\partial z) \quad (3)$$

where $g_t\,(x,y,z)$, $g_s(x,y,z)$ are grey level function of the target and the search windows; $n(x_t,y_t,z_t)$ is error vector; $\frac{dg_s}{dx}, \frac{dg_s}{dy}, \frac{dg_s}{dz}$ are gradients in x, y and z directions, which can be declared as g_x, g_y, g_z.
If both the radiometric quality and the geometrical differences are considered, the equation (2, 3) can be written as:

$$g_t(x_t,y_t,z_t)=h_0+h_1*g_s[(a_0+a_1x+a_2y+a_3z), (b_0+b_1x+b_2y+b_3z),(c_0+c_1x+c_2y+c_3z)] \quad (4)$$

$$\begin{aligned}&\Delta g(x_i,y_j,z_k)+v(x_i,y_j,z_k)=\\&g_x(x_i,y_j,z_k)da_0+x_ig_x(x_i,y_j,z_k)da_1+y_jg_x(x_i,y_j,z_k)da_2\\&+z_kg_x(x_i,y_j,z_k)da_3+g_y(x_i,y_j,z_k)db_0+x_ig_y(x_i,y_j,z_k)db_1\\&+y_jg_y(x_i,y_j,z_k)db_2+z_kg_y(x_i,y_j,z_k)db_3+g_z(x_i,y_j,z_k)dc_0\\&+x_ig_z(x_i,y_j,z_k)dc_1+y_jg_z(x_i,y_j,z_k)dc_2+z_kg_z(x_i,y_j,z_k)dc_3\\&+dh_0+g_1(x_i,y_j,z_k)dh_1\end{aligned} \quad (5)$$

where a_0, a_1, a_2, a_3, b_0, b_1, b_2, b_3, c_0, c_1, c_2 and c_3 are unknown parameters for affine transformation; h_0 and h_1, are unknown coefficients for radiometric correction.

However, there is a need to give initial value to the matcher. The values are acquired by transforming PRISM stereo images to ground coordinates using geometric model (equation 7). This process is called ortho-rectification. In the ortho-rectification conversion process, geometric corrected low resolution DEM data provided by geographical survey institute (GSI) are used for both of backward and nadir look images. When the same place of both images is located to same coordinate, the selected pixels can be input to matching model.

4.2 DSM Generation

In the general DLT model (equation 6), when the image coordinates (u, v) of the correspondence point of the stereo pair are know, the ground object coordinates (X, Y, Z) can be solved by least squares method.

$$\begin{aligned}u &= \frac{b_1X+b_2Y+b_3Z+b_4}{b_9X+b_{10}Y+b_{11}Z+1}\\ v &= \frac{b_5X+b_6Y+b_7Z+b_8}{b_9X+b_{10}Y+b_{11}Z+1}\end{aligned} \quad (6)$$

For two stereo images, the DLT model can be demonstrated by equation (7).

$$\begin{aligned}U_n&=\frac{a_{n1}X+a_{n2}Y+a_{n3}Z+a_{n4}}{b_{n1}X+b_{n2}Y+b_{n3}Z+1}\\V_n&=\frac{a_{n5}X+a_{n6}Y+a_{n7}Z+a_{n8}}{b_{n1}X+b_{n2}Y+b_{n3}Z+1}\\U_b&=\frac{a_{b1}X+a_{b2}Y+a_{b3}Z+a_{b4}}{b_{b1}X+b_{b2}Y+b_{b3}Z+1}\\V_b&=\frac{a_{b5}X+a_{b6}Y+a_{b7}Z+a_{b8}}{b_{b1}X+b_{b2}Y+b_{b3}Z+1}\end{aligned} \quad (7)$$

where U_n, V_n are image coordinates of nadir image and U_b, V_b are image coordinates of backward image.

4.3 Verification of 3D Measurement

The required coefficients for 3D projective transformation are calculated from well-distributed 14 GCPs. Over 90% of corresponding points from the selected area are matched when we generate stereo image matching. 3D coordinates were calculated using those matched points. Finally, DSM is generated from 3D coordinates. As of accuracy evaluation, calculated 3D coordinates are validated with GPS-VRS data. Differential errors are calculated based on Z values 14 GCPs of both data (table 4).

5. RESULTS AND DISCUSSION

When the model generated less error occurrence along with x direction in the image, the big errors are occurred in y direction. As of look, Nadir has more consistency then other oblique looks (forward and backward) table 2.

	GCP		CP	
	U(pixel)	V(pixel)	U(pixel)	V(pixel)
Forward	1.56	1.3	2.13	1.53
Nadir	0.54	8.48	1.28	8.26
Backward	1.65	7.15	2.01	7.03

Table 2: RPC model residual error around GCP and CP

In other hand, when the 3D projective function is used as transformation model, all three looks have less than one pixel accuracy around GCP. However, the errors are grown around check point (CP) (table 3).

	GCP		CP	
	U(pixel)	V(pixel)	U(pixel)	V(pixel)
Forward	0.29	0.26	1.25	0.95
Nadir	0.25	0.21	1.59	1.28
Backward	0.27	0.26	1.91	0.89

Table 3: 3D Projective residual error around GCP and CP

Comparison results of height (Z) values are shown in table 4. The maximum error around check points is 3.5 meters with root mean squares error of 2.4 meters.

GCP	Z (GPS)	Z (ALOS-PRISM)	Error
1	297.956	299.493	-1.537
2	291.025	291.398	-0.373
3	290.097	287.595	2.502
4	327.953	324.479	3.474
5	325.426	323.69	1.736
6	312.236	309.774	2.462
7	306.098	307.069	-0.971
8	309.322	312.575	-3.253
9	309.049	311.938	-2.889
10	315.088	311.91	3.178
11	319.438	317.35	2.088
12	324.52	322.466	2.054
13	289.559	291.716	-2.157
14	317.969	315.71	2.259
		RMSE	**2.364**

Table 4: 3D Mesurement errors by DLT method

We can found some noises in the generated DSM data when the place has low contrast such as forests or flat area. The miss-matching errors could be occurred in such area (figure 4). Therefore, the accuracy of check points will be growing with the advanced of high contract area.

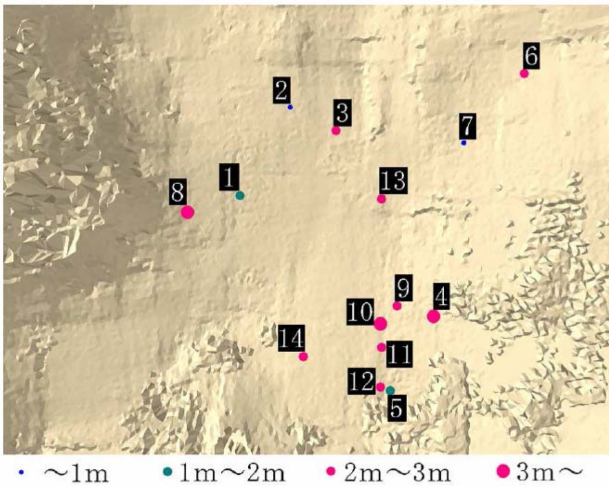

Figure 4: Location and error size of check point.

6. CONCLUSION

The study demonstrated that ALOS-PRISM DSM data has potential to monitor slope failure disaster when the failure area is greater than 6 m^2. It was shown that the main requirement of the study is successes by the research.

Even the accuracy produced by the model is enough to monitor 30 cubic meters landslide, the investigated area need more accurate one because of only a few cm/year land displacement are contributing to the sliding land. However, this could be a very useful method to observe slope failure displacement without visiting the site which had been occurred. The over all accuracy of 3D measurement give 2.5 meters; it is almost similar to the ground spatial resolution of the PRISM data. The measurement produced adequate accuracy to produce 1:25,000 scales in topographic map. However, some problem still remaining for future works such as to reduce processing time, to improve accuracy in low contract area, and to study impossibility of GCP collection in the close forest area.

7. FUTURE WORKS

In future, Airborne Laser Scanner DSM data will be used as reference to investigate the consistency of PRISM DSM data. It is possible to investigate more models and it can be verified by drawing error vectors of each model to represent consistency of model based on selected area.

The generated DSM are based on random points; it promotes the difficulty to calculate displacement. However, it problem could be solved by converting it to triangulated irregular network (TIN) model. TIN data is ease to calculate the displacement of slope failure with evaluation grids.

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