VERIFICATION OF DSM PRODUCT BY USING TERRASAR-X AND EROS-B STEREO PAIR IMAGES

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ABSTRACT: We performed the generation and the verification of digital surface model (DSM) derived from TerraSAR-X and EROS-B high resolution stereo pair images, respectively. These stereo pair images were geometrically corrected by means of quadratic polynomial model with ground control points (GCPs) observed by RTK-GPS measurement. The stereo matching process was performed by adopting a normalized cross-correlation algorithm. The correlation coefficient was calculated in small region between the stereo pair images over the each stereo pair images. In addition, a coarse-to-fine strategy was adopted to reduce the time for matching process and to improve matching performance. The parallax in each stereo pair image was derived from the stereo geometric model for the calculation of altitude using each stereo pair image. In this processing, the altitude was calculated by using the geometric parameters such as parallax, incidence and azimuth angles in each pixel of the stereo pair images. The validation was performed by comparison with GCPs and digital elevation model (DEM) produced by using the conventional aerial stereo pair photographs. The altitude range of the test site is from 0 m to 693 m. The residual errors of DSM of TerraSAR-X and EROS-B were distributed from -18.6 m to +11.8 m and from -15.7 m to +19.0 m in comparison with GCPs, respectively. The root mean square errors were 11.9 m and 9.1 m, respectively. And also, the root mean square errors were 7.9 m and 7.0 m in comparison with the reference DEM, respectively. In addition, we have developed 3-D viewer system using high resolution satellites imageries and DSM for the visualization and geospatial calculation. These results show the possibility of DSM generation and utilization by using high resolution SAR and optical satellites data.

1. INTRODUCTION

Digital Surface Models (DSMs) are effective information in precision mapping based on satellite remotely sensed data. The DSMs are used for urban planning, disaster monitoring, resource management. The elevation data is also used for Three-Dimentional (3D) analysis integrated with remote sensing imageries.In order to derive the elevation, an automatic stereo matching tequnique has been used. There are two major matching tequniques, that is, a feature-based and an area-based. In this study, we adopted the feature-based tequnique with normalized cross-correlation because the tequnique is widely used for synthetic aperture radar (SAR) and optical sensor (OPS) stereo pair images.

In recent years, high resolution remote sensing imageries have been used for a precise mapping besides a conventional mapping. TerraSAR-X and EROS-B have a high resolution SAR and OPS, respectively. TerraSAR-X provide images with some mode and look angles. TerraSAR-X High resolution Spotlight (HS) mode obtains images with up to 1 meter resolution. EROS-B provide images on Nadir with 0.7 meter resolution or at oblique angles of up to 45 degrees.These sensors can provide stereo pair images for DSM generation. The DSM generation by SAR stereo images, radargrammetry, has been mainly used by RADARSAT stereo pair data (Toutin, 2004a). As for high resolution OPS stereoscopic, DSM geration has been mainly used by Quickbird or IKONOS stereo pair images (Toutin, 2004b and Eisenbeiss et al., 2004). Therefore, the performance of DSM generated by stereo pair image of TerraSAR-X and EROS-B has not been verified yet. The aim of this study is to verify the accuracies of DSMs generated by TerraSAR-X and EROS-B stereo pair images, respectively. The verification method is to compare DSM generated by aerial photographs and DSM generated by TerraSAR-X and EROS-B, respectively.

2. DATASET

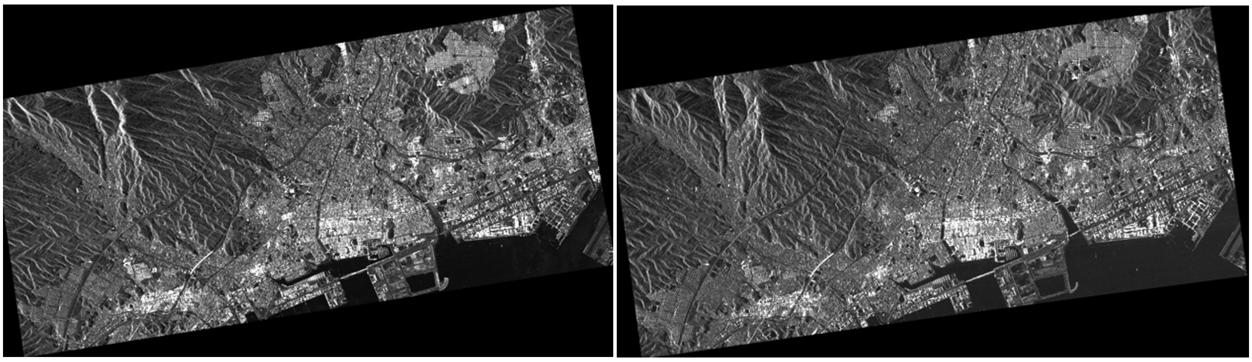
2.1 Test Site and Used Data

The test site is Hiroshima City in Japan which include densely built-up, residential, agricultural and closely next to mountain area. The altitude range is from 0 m to 693 m. Table 1 shows the specification of TerraSAR-X and EROS-B stereo pair images used in this study.

TerraSAR-X is a high resolution X-band SAR satellite launched in 2007. TerraSAR-X has some mode and look angles. We selected the High resolution Spotlight (HS) mode, which is the highest resolution mode. Figure 1 shows the images of TerraSAR-X stereo pair images. The resolution of TerraSAR-X HS mode is approximately 1.0 m with 10 km swath. EROS-B is a high resolution OPS satellite launched in 2006. The resolution of EROS-B is approximately 0.7 m with 7 km swath. Figure 2 shows the images of EROS-B stereo pair images. GPS observation was also performed to set up Ground Control Points (GCPs) and to evaluate the DSMs generated by the stereo pair images.

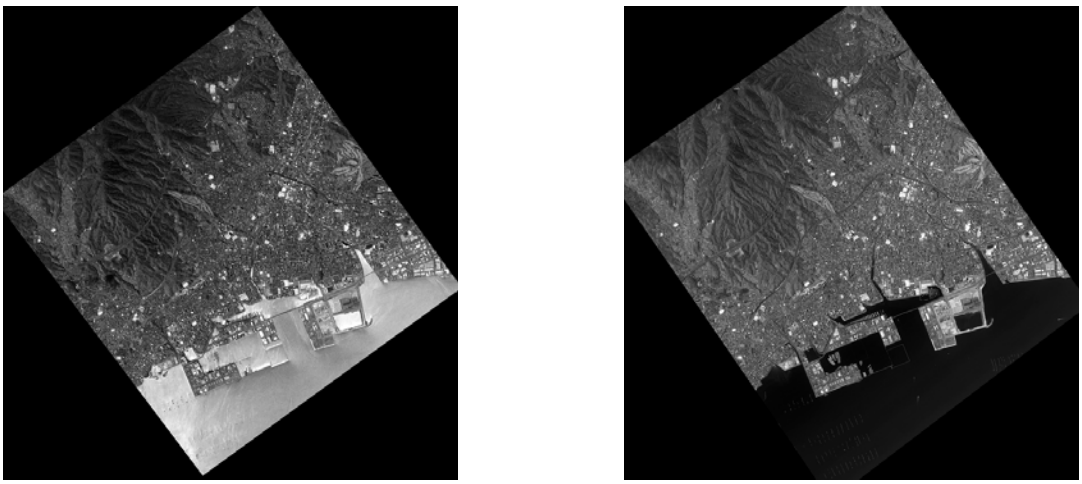
Table 1. Specification of satellite images used in this study.

Satellite	TerraSAR-X		EROS-B	
Acquisition date	17/02/2009	22/02/2009	17/04/2009	17/04/2009
Acquisition mode	High resolution Spotlight		Basic scene (Stereo)	
Number of Pixels	16564	24128	10148	10148
Number of Lines	7095	10532	7409	8242
Pixel spacing (m)	0.75	0.50	0.74	0.74
Center incidence angle (deg.)	29.74	45.34	26.68	26.83



(a) 17 February 2009 (b) 22 February. 2009

Figure 1. TerraSAR-X stereo pair images.



(a)17 April 2009 (b) 17 April 2009

Figure 2. EROS-B stereo pair images.

3. GEOMERTIC REGISTRATION FOR STEREO PAIR IMAGES

Generating DSM from stereo pair images requires the use of a geometric model (rigorous physical sensor model) or GCPs. We use GCPs generated by the GPS observation. The GCPs are collected with UTM (zone 53N, datum WGS84) coordinate system.

The stereo pair images were corrected using the following two equations with the GCPs. The first equation is linear polynomial model that the distortions of horizontal and vertical assume constant in the whole image.

$$\begin{aligned} x &= a_1 \cdot u + a_2 \cdot v + a_3 \cdot h + a_4 \\ y &= b_1 \cdot u + b_2 \cdot v + b_3 \cdot h + b_4 \end{aligned} \quad (1)$$

The second equation is quadratic polynomial model that the distortions of horizontal and vertical assume nonlinear in the whole image.

$$\begin{aligned} x &= a_1 \cdot u^2 + a_2 \cdot v^2 + a_3 \cdot h^2 + a_4 \cdot u \cdot v + a_5 \cdot u \cdot h + a_6 \cdot v \cdot h + a_7 \cdot u + a_8 \cdot v + a_9 \cdot h + a_{10} \\ y &= b_1 \cdot u^2 + b_2 \cdot v^2 + b_3 \cdot h^2 + b_4 \cdot u \cdot v + b_5 \cdot u \cdot h + b_6 \cdot v \cdot h + b_7 \cdot u + b_8 \cdot v + b_9 \cdot h + b_{10} \end{aligned} \quad (2)$$

where x and y are variables of map coordinates, u and v are values of image coordinates, h is the altitude obtained from GPS, a_n and b_n are coefficients of transformation. Table 2 and 3 show the Root Mean-Square Error (RMSE) result of TerraSAR-X and EROS-B, respectively. As the result, the RMSE of quadratic polynomial model is lower than that of linear polynomial model in these data. The incidence angle of TerraSAR-X image is different between near range and far range. Therefore, the quadratic polynomial model is effective because the distortion of TerraSAR-X is not constant in whole image. However, the residual error of registration is high in TerraSAR-X because the selection of precision tie point is difficult. EROS-B enables to acquire single pass stereo imaging in asynchronous mode by slewing the platform in the along-track direction. Therefore, the quadratic polynomial model is also effective for EROS-B stereo pair images.

Table 2. RMSE of TerraSAR-X stereo pair images for registration.

	Linear polynomial model				Quadratic polynomial model			
	TerraSAR-X Scene#1		TerraSAR-X Scene#2		TerraSAR-X Scene#1		TerraSAR-X Scene#2	
	Pixel(m)	Line(m)	Pixel(m)	Line(m)	Pixel(m)	Line(m)	Pixel(m)	Line(m)
RMSE	5.1	4.7	5.9	6.6	3.3	4.0	4.6	4.9

Table 3. RMSE of EROS-B stereo pair images for registration.

	Linear polynomial model				Quadratic polynomial model			
	EROS-B Scene#1		EROS-B Scene#2		EROS-B Scene#1		EROS-B Scene#2	
	Pixel(m)	Line(m)	Pixel(m)	Line(m)	Pixel(m)	Line(m)	Pixel(m)	Line(m)
RMSE	5.8	9.0	12.3	5.5	1.4	1.4	1.9	1.3

4 GENERATION OF DIGITAL SURFACE MODEL

4.1 Methodology of Extraction of Height Information from Stereo Pair Images

The technique of DSM extraction is basically the same between TerraSAR-X and EROS-B. The technique is based on conventional photogrammetry. However, the geometry of SAR and OPS is different by the difference of acquisition performance. Figure 3 and 4 show the stereo geometries for SAR and OPS. The altitude of a target derives from parallax differences as perceived from two different points of view. The altitude derived from SAR (h_{SAR}) is calculated in Eq.(3)

$$h_{SAR} = \sqrt{\frac{D^2}{\cot i_1^2 + \cot i_2^2 - 2 \cdot \cot i_1 \cdot \cot i_2 \cdot \cos\theta}} \quad (3)$$

and the altitude derived from OPS (h_{OPS}) is calculated in Eq.(4)

$$h_{OPS} = \sqrt{\frac{D^2}{\tan i_1^2 + \tan i_2^2 - 2 \cdot \tan i_1 \cdot \tan i_2 \cdot \cos\theta}} \tag{4}$$

where D is distortion of a target in the stereo pair image, i_1 and i_2 are incidence angles, θ is difference of imaging azimuth in stereo pair images, respectively.

The incidence angles of TerraSAR-X are described in annotation file at four corner points and center point. The incidence angle at each pixel is calculated by quadratic interpolation. The azimuth angle of TerraSAR-X measures from the registration image as a constant value.

The camera model software for EROS-B provided by Imagesat International N.V. calculates the satellite position and the camera angles at each pixel. The incidence and azimuth angles are converted from the camera model information.

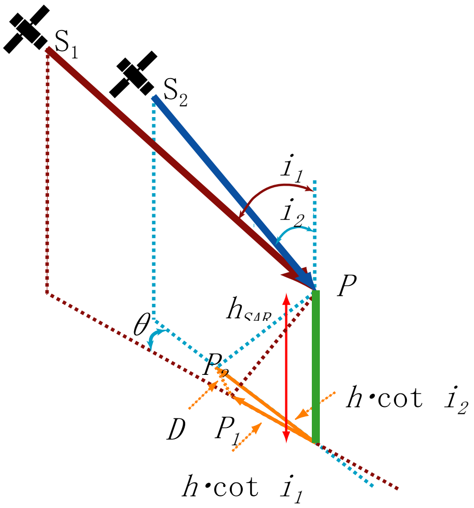


Figure 3. Geometry for the height extraction using SAR stereo pair images.

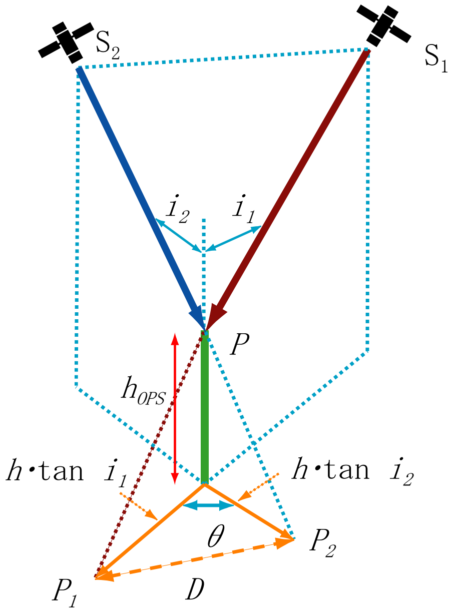


Figure 4. Geometry for the height extraction using OPS stereo pair images.

4.2 Matching process

The matching operation of the stereo pair images plays a key role in the DSM generation processing. The matching operation is based on the identification of the corresponding point between the stereo pair images. The normalized cross-correlation is adopted because the algorithm has achieved in some literatures (Suga et al., 2003 and Takaku et al., 2007). In the algorithm, the correlation coefficient is calculated in small region between the stereo pair images over the images. The matching process consumes a great deal of time because the computation of the cross-correlation is time-consuming and the identification of the corresponding point requires the searching in large area. A coarse-to-fine strategy is used to reduce the matching process time and to improve matching performance. The basic principle is used pyramid layers. At each layer, the stereo pair images are degraded by averaging pixels. Pixels of the stereo pair images were averaged by 32 × 32 (1/32), 16 × 16 (1/16), 8 × 8 (1/8), 4 × 4 (1/4), and 2 × 2 (1/2) pixels as a part of pyramidal layers. At first, the matching process of the stereo image pair is performed on 1/32 layer. The approximate parallax can be obtained by this matching process in a short time than the other layer level comparatively. The parallax derived from the process is able to use a prediction of the offsets for the processing in the next layer. Secondly, the matching processes are performed from 1/6 to 1/2 referring to the approximate parallax derived from previous layer level. Thirdly, the parallax at pixels to generate altitude is obtained on a final layer. The coarse-to-fine strategy reduces the computational time, and the matching errors that cause the abnormal value of altitude in mountainous area such as a homogeneous land cover. Finally, ortho-rectification was performed by the altitude and the incidence angle in each pixel for generating DSM.

4.3 Verification of DSMs

The verification of DSMs generated by the TerraSAR-X and the EROS-B stereo pair images is respectively assessed by comparison with the altitude obtained by GPS observation and the DEM generated by aerial photographs. The grid interval of these altitude data is 1.4 m. The DEM generated by aerial photographs was resampled from 1 m to 1.4 m with bi-linear interpolation. Table 4 shows the comparison of the altitude derived from GPS surveying and DSM generated by stereo images. The residuals were calculated by subtracting the reference DEM from DSM in each GCP. The RMSE of altitude derived from TerraSAR-X, EROS-B and Aerial photograph were 7.9 m, 7.0 m and 1.6 m, respectively. The residual errors of DSM of TerraSAR-X and EROS-B were distributed from + 11.8 m to –18.6 m and from + 19.0 m to –15.7 m, respectively. As for the reference data, the residual errors of DEM derived from aerial photograph were distributed from + 1.7 m to –5.1 m.

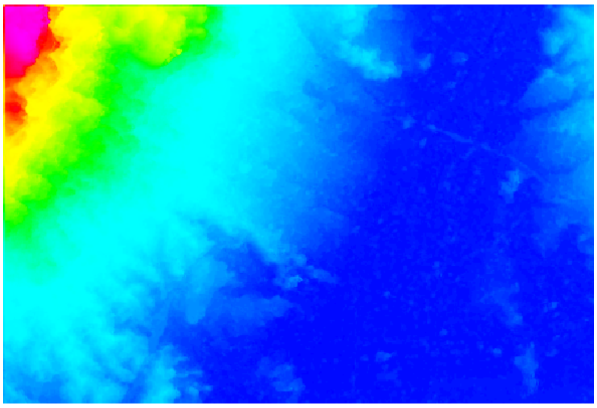
Table 4. Comparison of the altitude derived from GPS surveying and DEM and DSM generated by stereo images.

GCP#	Altitude (m)	Residual of DEM in Aerial photograph (m)	Residuals of DSM in TerraSAR (m)	Residual of DSM in EROS-B (m)
1	40.9	0.1	-3.9	4.1
2	4.5	0.5	-0.5	-0.5
3	10.5	-2.5	-1.5	3.5
4	4.7	-1.7	-0.7	-0.7
5	4.3	-0.3	-0.3	3.7
6	5.1	-0.1	-1.1	0.9
7	14.3	-0.3	-2.3	-1.3
8	46.7	0.3	-14.7	-5.7
9	139.6	0.4	-18.6	-3.6
10	90.8	-1.8	-3.8	-1.8
11	207.2	-0.2	-13.2	-7.2
12	2.1	0.9	N/A	-1.1
13	2.3	0.7	2.7	1.7
14	90.7	1.3	-0.7	14.3
15	3.2	-1.2	11.8	-1.2
16	5.3	1.7	2.7	9.7
17	55.5	1.5	0.5	-1.5
18	2.1	-2.1	5.9	-0.1
19	115.7	N/A	N/A	-15.7
20	638.0	1.0	N/A	19.0
21	108.1	-5.1	-8.1	-5.1
22	206.8	1.2	-12.8	-1.8
RMSE		1.6	7.9	7.0

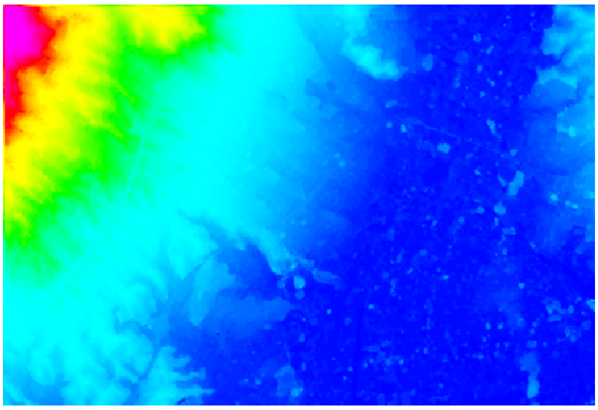
The verification of the DSMs is achieved by comparing the altitude derived from DSMs to that of reference DEM within the identical area of TerraSAR-X and EROS-B as shown in Figure 5. The area includes 3,567 pixel × 2,407 line for the verification. The right part of the image is residential area and the left part of the image is mountainous area. The altitude range is from 0 to 693 m in the test verification site. The DSM images were similar to the reference DEM in the whole area. The RMSE of residuals were 11.9 m in TerraSAR-X, 9.1 m in EROS-B in comparison with reference DEM of aerial photograph. The DSMs measure higher than the reference DEM in residential and mountainous area because DSM contains the building and the tree height, etc. Other factors of the altitude differences, there are misregistrations derived from registration in section 3.1 and ortho-rectified with altitude estimated by stereo pair images.

5 CONCLUSIONS

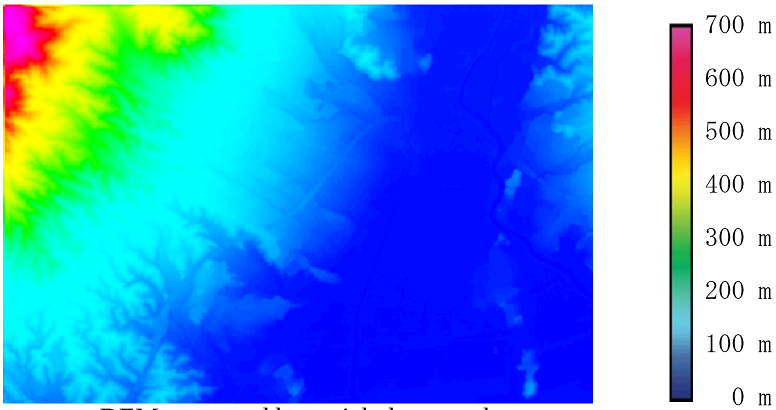
This study performed on the generation of automatic DSM (Digital Surface Model) by stereo pair images of TerraSAR-X and EROS-B high-resolution satellite data, respectively. The authors attempted the registration of the stereo pair images with GCPs based on the GPS ground surveying. The residual error of registration in TerraSAR-X was estimated 3.95 m in the mean RMSE at pixel direction and 4.45 m in the mean RMSE at line direction on stereo pair images by Quadratic polynomial model. The residual error of registration in EROS-B was estimated 1.65 m in the mean RMSE at pixel direction and 1.35 m in the mean RMSE at line direction on stereo pair images by Quadratic polynomial model. A coarse-to-fine strategy is used to reduce the matching process time and to improve the matching performance. In this experiment, the strategy reduced occurrence of the matching errors in mountainous area covered with forests. The RMSE of DSM of TerraSAR-X and EROS-B in comparison with the reference DEM were 7.9 m and 7.0 m, respectively. These results show the possibility of TerraSAR-X and EROS-B for DSM generation. Furthermore, will focus on precise registration including mountainous area and verify the DSMs in comparison with precise DSM derived from LIDAR.



DSM generated by TerraSAR-X



DSM generated by EROS-B



DEM generated by aerial photograph

Figure 5. DEM and DSM generated by aerial photograph, TerraSAR-X and EROS-B stereo pair images

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