UPDATE OF DEM IN URBAN AREAS USING SPOT STEREO PAIR

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ABSTRACT

The authors attempted to update DEM by using satellite images in some part of the urban areas where current DEM does not coincide with actual topography. SPOT panchromatic stereo pair images were used to perform partial updating of current DEM data because of high accuracy for DEM computation and easiness for data handling. As a model for height computation, a simple regression model was employed to compute height from the parallaxes in SPOT panchromatic stereo pair images. The error for height computation by the regression model was 27.3 meters in R.M.S.. The result of this study proved that DEM update is significantly important to generate up-to-date urban spatial information.

1 INTRODUCTION

Digital Elevation Model (DEM) is now one of the important data sources for environmental analysis by combining with satellite remote sensing data. Nowadays, Geographical Survey Institute of Japan (GSI) has completed to develop DEM with 50 m spatial resolution in whole areas of Japan and these DEM are used widely for various kinds of environmental analysis.

However, present DEM were made from the maps some years ago and some of them are old compared with present maps. Especially, in urban areas, urban development has made some topographic conditions changed from the previous conditions and some part of DEM does not coincide with the actual topographic conditions. In this paper, the author attempted to update DEM by using satellite images in some part of the urban areas where current DEM does not coincide with actual topography.

Several approaches are considered to perform DEM generation by satellite data, however, in this study, SPOT panchromatic stereo pair images are used to perform partial updating of current DEM data because of high accuracy for DEM computation and easiness for data handling.

2 METHOD AND ACCURACY FOR HEIGHT MEASUREMENT

Currently the following three methods are considered to be available to generate DEM using satellite images.
(1)Stereo pairs by optical sensors with pointing function like SPOT.
(2)Stereo-SAR by variable incidence angle SAR sensors like RADARSAT.
(3)SAR interferometry by repeat-pass SAR data pairs.

The accuracy (height resolution: Δh) for DEM generation by stereo pairs of optical sensors is defined as follows (see Figure 1);

$$\Delta h = \Delta P / (B/H) \qquad (2.1)$$

where, ΔP means spatial resolution of the image, B means orbit interval (baseline length), H satellite altitude, and (B/H) base/height ratio. For SPOT panchromatic data, Δh becomes 20 meters when base/height ratio is 0.5 because ΔP is 10 meters.

For stereo-SAR by RADARSAT, Δh is defined as follows (see Figure 1);

$$\Delta h = \Delta P / \left| 1/\tan\theta_1 - 1/\tan\theta_2 \right| \qquad (2.2)$$

where, θ_1 and θ_2 are incidence angles for each of stereo-SAR images. For RADARSAT fine mode data, the highest spatial resolution data among RADARSAT data, the range of incidence angle is from 38 to 46 degree and the effective range resolution is about 10 meters, although an actual pixel spacing of fine mode data is 3.75 or 6.25 meters. Therefore Δh results in about 32 meters.

As to SAR interferometry, it is difficult to define Δh because height is generated from continuous two dimensional phase patterns. However, by some conventional studies (i.e. Suga and Takeuchi *et al.,* 1998), actual height error has been reported to be at least 40 to 50 meters when JERS-1 SAR data pair are used for the test site of Japan Islands.

As summarized above, currently the stereo pairs by optical sensor images are considered to bring the best accuracy for DEM generation. For optical sensors, data acquisition of cloud-free stereo pair is sometimes difficult due to weather conditions. However, the objective of this study is to update a part of DEM and optical sensors still can be used in many situations for the purpose of this study. Therefore SPOT panchromatic stereo pairs are used in this study.

3 HEIGHT UPDATE BY SPOT STEREO PAIR

3.1 Method

Generally height measurement by SPOT stereo pair images has employed satellite orbit information and geometric observation model for generating DEM. However, in this study, a simple regression model is employed because of the following reasons;

(1) The study objective is to update DEM, so current DEM is available in the study.
(2) Relatively complicated process is required with geometric observation model.
(3) Some commercial packages are available with satellite orbit information, however, they can not use SPOT data archived by NASDA.
(4) A preliminary study proved that geometric distortion of SPOT panchromatic data, the origin of stereo parallax, is approximated with the error of one pixel by a simple regression model in which only one height variable is added to a conventional geometric transform model without considering height (Ogawa and Takeuchi *et al.,* 1999, Suga and Oguro *et al.*,1999, Suga and Ogawa *et al.,*1999).

The regression model is defined as follows;

$$h = a_1 DP + a_2 DL + a_3 P + a_4 L + a_5 \qquad (3.1)$$

where, h means height, DP and DL are parallax in pixel and line direction, P and L are pixel and line coordinate in the standard image which is overlaid onto DEM, and $a_1 \sim a_5$ are regression coefficients.

For deciding above regression coefficients, first a standard image with no geometric distortion by height is overlaid onto the current DEM. A Landsat TM image is used as the standard image in this study. Next, each image of a SPOT panchromatic stereo pair is registered onto the standard image without considering height (initial registration). Then the triplets of image tie points in the three images, standard and stereo pair images after initial registration, are acquired uniformly from the whole areas of the images. Finally the regression coefficients are computed by the least square method with the parallaxes and the standard image coordinate values obtained from the triplets. It is necessary to exclude the areas where some topographic changes are expected by apparent land use changes when the triplets are acquired.

3.2 Result of Regression

As the test stereo pair data, SPOT panchromatic data (K-J: 317-281) acquired on Dec. 30, 1998 and on Jan. 31, 1999 were used. The incidence angle at the image center is R10.4 and L17.2 degree respectively, which results in the base/height ratio about 0.5. The test site is the western part of Hiroshima City and just the same area as 1:50,000 topographic map "Hiroshima". A Landsat TM image (Path-Row:112-35) acquired on May 22, 1998 was used as the standard image.

First, the current DEM in the test site with 50 meters grid by GSI was resampled with bi-linear interpolation to generate DEM with 10 meters resolution. Then the TM image was rectified and resamapled with cubic convolution to generate 10 meters standard image overlaid onto the 10 meters DEM. The SPOT panchromatic stereo pair images were initially registered onto the standard TM respectively and a total of 39 triplets were acquired to decide the regression coefficients.

Table 1 shows the result of regression coefficients values. The R.M.S. error for height approximation by Eq. (3.1) was 27.3 meters. As the base/height ration is about 0.5, the height resolution of this pair is about 20 meters and this almost coincides with the regression coefficient of DP (19.67). The actual error, 27.3 meters, is relatively bigger than this height resolution, however, this error value is considered reasonable because the error for approximating height distortion of SPOT is about 1.3 pixel (13 meters) in maximum (Suga and Ogawa *et al.*, 1999). Figure 2 shows the overlaid image of the SPOT panchromatic stereo pair after initial registration.

Table 1. Result of regression for Eq.(3.1).

a_1	a_2	a_3	a_4	a_5
19.671	6.164	-0.1389	0.0007582	232.22
Height error (R.M.S.) : 27.254 meters				

3.3 Result of Update

The current DEM was updated partially using the regression coefficients obtained in 3.2. First, several areas where topographic conditions are expected to change were selected by visual interpretation of the SPOT and TM images. Then the image matching with the area correlation were executed in every pixel locations in the selected areas to derive pixel and line parallaxes and the height values were re-computed from the regression coefficients in Table 1.

In this process, the image coordinate in the stereo pair is slightly different from the image coordinate in the standard image and DEM because of the height distortion of the stereo pair. This difference is corrected by the regression coefficients for height distortion, which is also performed using the triplets of image tie points. This correction still results in some error when actual topography changes, which was neglected in this study.

In addition, the updated height jumped around 20 meters between adjacent pixels, which was considered caused by the regression coefficient of pixel parallax (see Table 1) and 10 meters resolution of SPOT panchromatic images. These discontinuous height patterns were eliminated using a smoothing operation with 9 x 9 moving window.

Figure 3 shows the current DEM and the updated DEM respectively. The updated areas are four, in all of them new housing lots were developed in mountain slopes. The topographic conditions in all four areas change into more flat and smooth topography, which suggests that slopes were changed into terraced housing lots by the land development.

3.4 Evaluation of DEM Update by Bird's Eye View Image

For the purpose of evaluating the effect by DEM update, bird's eye view images were created using the DEM before and after update. A fused image of the standard TM and one of the SPOT panchromatic stereo pair (Jan. 31, 1999) by the HSI transformation technique was used as the original image for bird's eye view. Figure 4 shows the examples of the bird's eye view images.

In Figure 4, new housing lots are seen made on the original mountainous topography in the bird's eye view by the current DEM (site A and B) , which are far from real views. On the other hand, the bird's eye view by the updated DEM gives more realistic views. Therefore, the DEM update is considered to be significantly important to generate up-to-date spatial information for understanding the present urban environmental conditions.

4 CONCLUSIONS

For the purpose of updating DEM which has become partly mismatched to the up-to-date topographic conditions, DEM update using a simple regression model with a SPOT panchromatic stereo pair was attempted. As the result, the height computation error was 27.3 meters and the updated DEM proved to be effectively used to generate more realistic bird's eye view images for understanding up-to-date urban environment.

This study employed SPOT panchromatic stereo pair, which also revealed some limitation due to its 10 meters resolution for more precise height measurement. Further studies with higher resolution satellite images like IKONOS are expected to improve height accuracy and to generate more precise urban spatial information.

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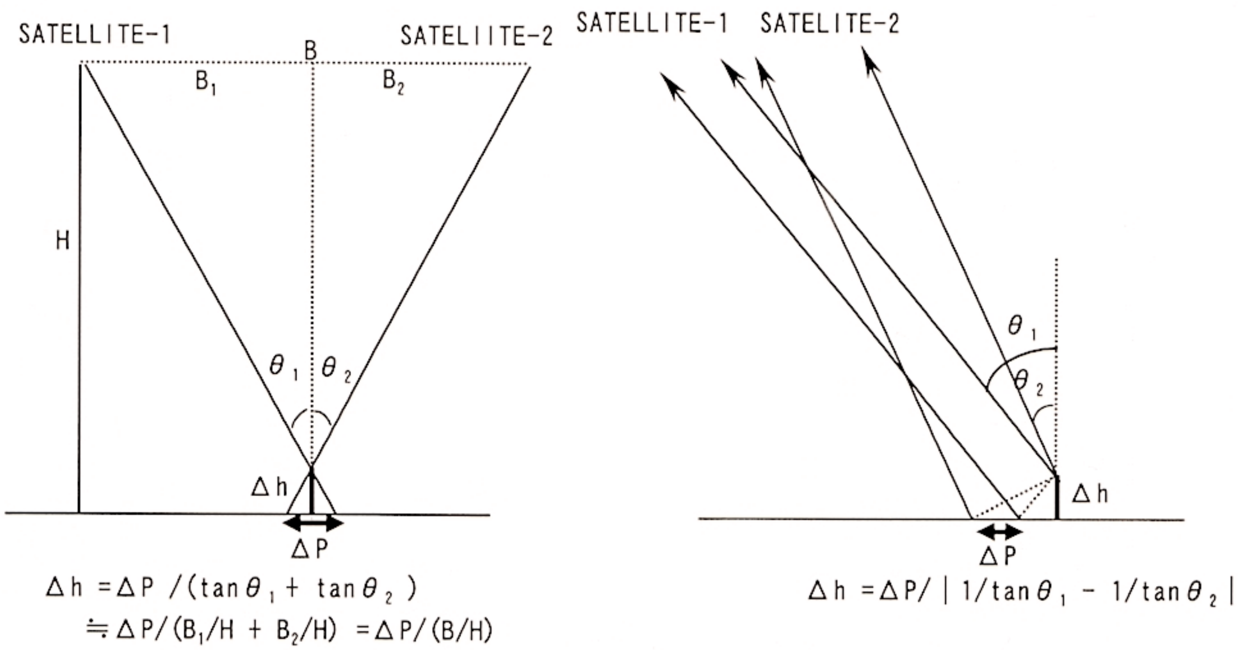
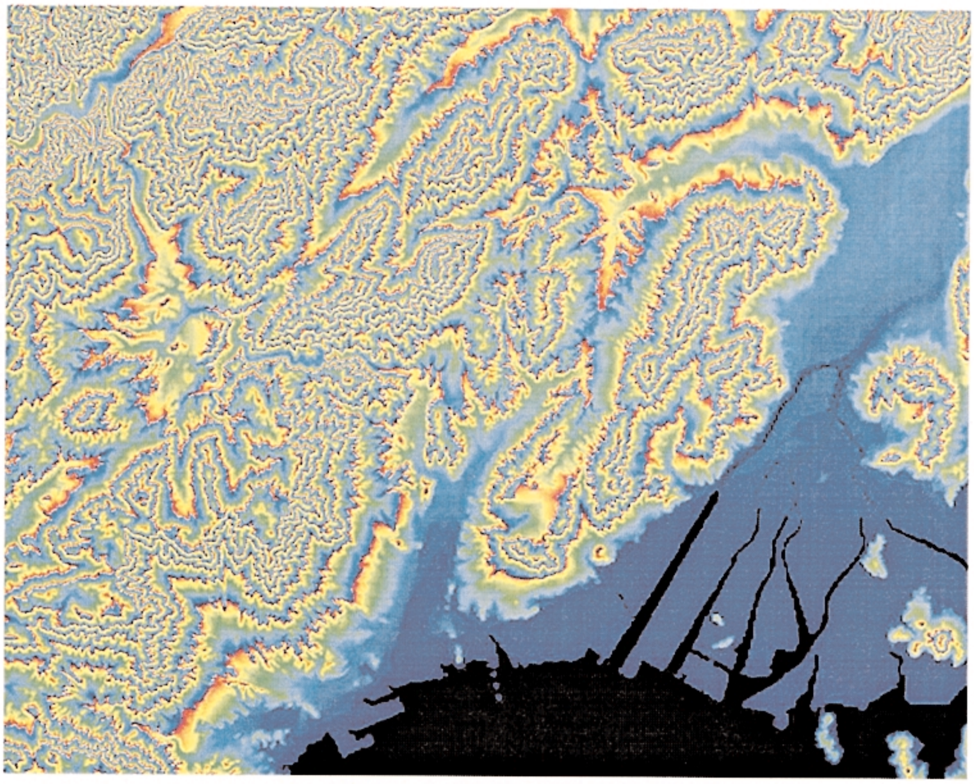
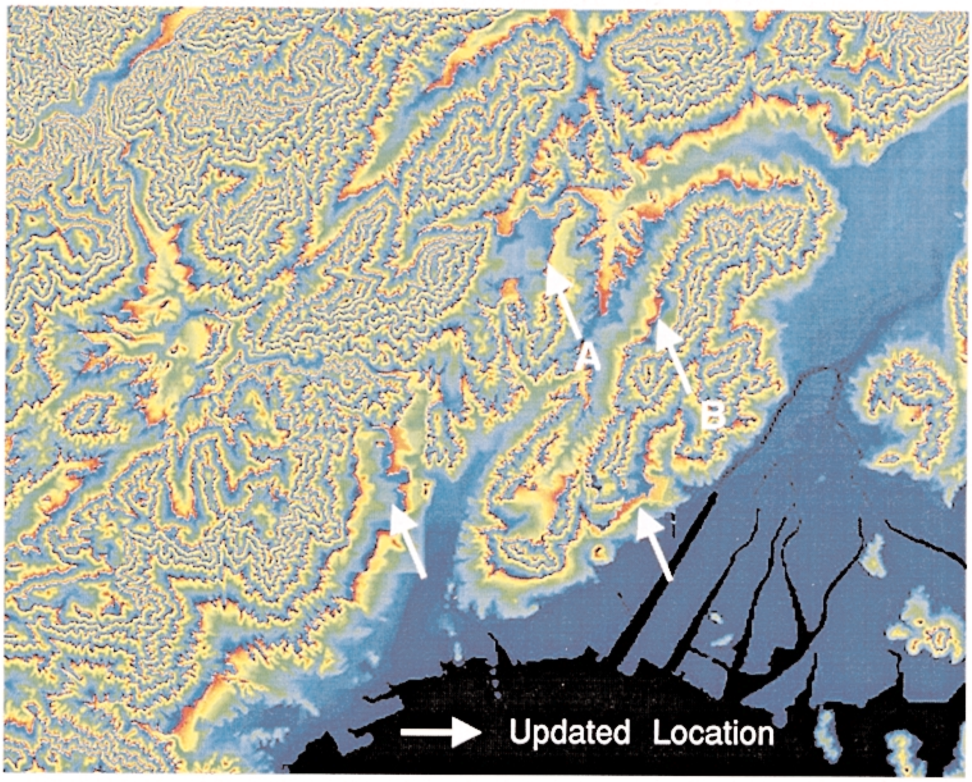


Figure 1. Height resolution (Δh) by stereo pair of optical sensors (left) and stereo-SAR (right).

Figure 2. Overlaid image of SPOT panchromatic stereo pair in the test site. ©CNES 1998/1999.

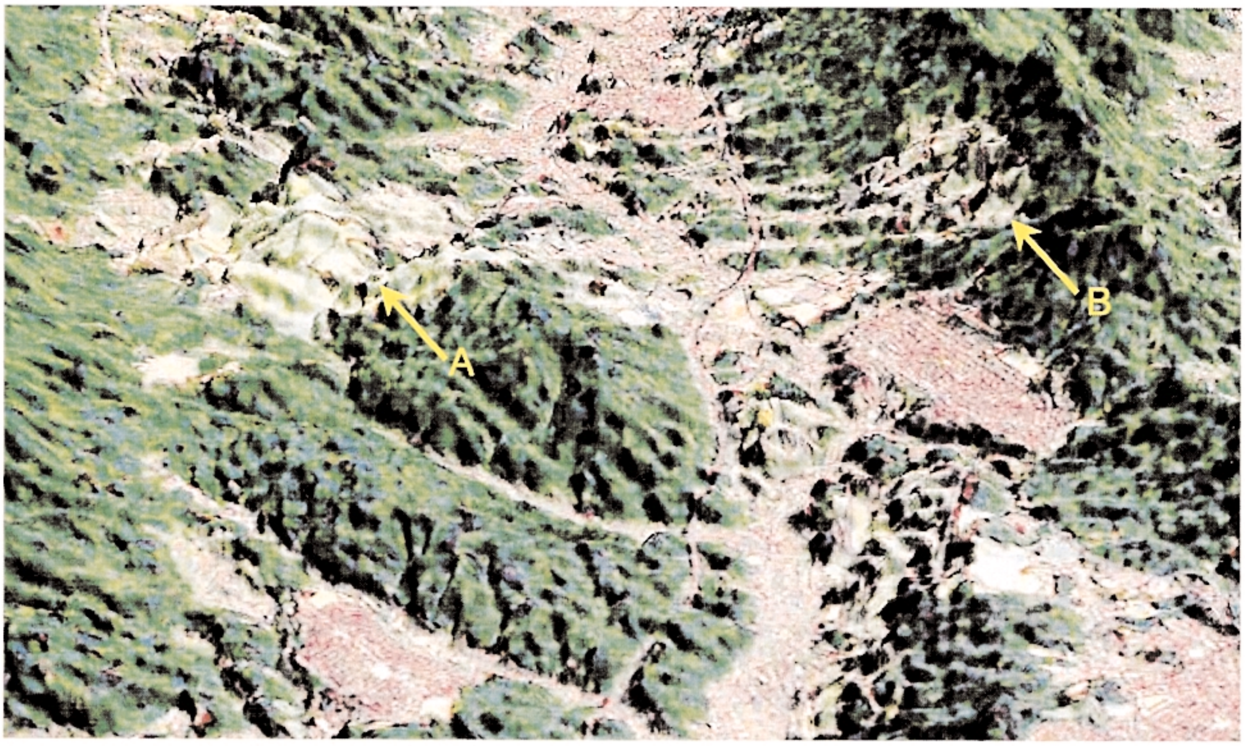


Current DEM by GSI in the test site (Wrapped by 100 meters interval).

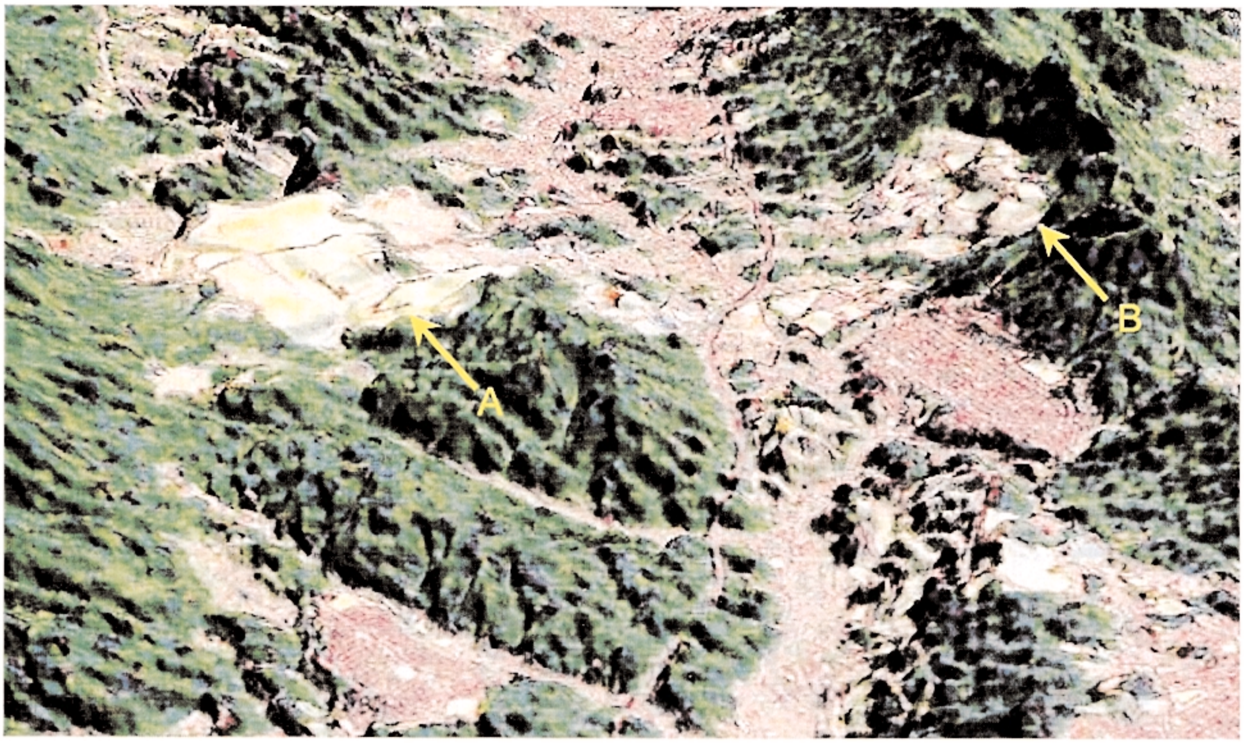


Updated DEM by SPOT stereo pair (Wrapped by 100 meters interval).

Figure 3. Current DEM (upper) and updated DEM by SPOT stereo pair (lower).



Bird's eye view image generated by using current DEM.



Bird's eye view image generated by using updated DEM.

Figure 4. Bird's eye view image generated by using current DEM (upper) and updated DEM (lower).