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# DIGITAL ELEVATION MODEL FROM PRISM-ALOS AND ASTER STEREOSCOPIC DATA

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**Abstract**. Digital Elevation Model (DEM) is a main source to produce contour map, slope, and aspect information, which is needed for other information such as disaster and water resources management. DEM can be generated by several methods. One of them is parallax calculation from stereoscopic data of optical sensor. Panchromatic Remote-Sensing Instrument for Stereo Mapping (PRISM) sensor from Advanced Land Observation Satellite (ALOS) satellite and Advance Space borne Thermal Emission and Reflection Radiometer (ASTER) sensor from Terra Satellite is Japanese optical satellite sensors which have ability to produce stereoscopic data. This study showed DEM generations from PRISM (2.5 m spatial resolution) and ASTER (15 m spatial resolution) stereoscopic data using image matching and collinear model based on Orthobase-pro software. The generated DEM from each sensor was compared to the DEM from Shuttle Radar Topography Mission (SRTM) X-C band with 30 m spatial resolution. The dependent on the pixel size from the DEM produced were also discussed. The result showed that both DEMs have similar elevation and distribution pattern to the referenced DEM, but DEM from PRISM had higher relative accuracy (RMSE is 6.5 m) and smoother pattern comparing to DEM from ASTER (RMSE is 10.2 m).

***Keywords****: ASTER, DEM, PRISM, SRTM, Stereoscopic satellite data*

## 1. Introduction

DEM is a main source to produce information of land physical parameters (elevation contour, slope and aspect), which are useful for supporting many kinds of activities such as disaster and water resources management. DEM can be generated by several methods. One of them is parallax calculation from stereoscopic data of optical satellite sensor. PRISM sensor from ALOS satellite and ASTER sensor from Terra Satellite are Japanese optical satellite sensors which have ability to produce stereoscopic data. ALOS satellite, was launched on January 24$^{th}$ 2006, is equipped with PRISM, AVNIR and PALSAR sensors. PRISM is a panchromatic radiometer with a wavelength of 0.52 to 0.77 μm and 2.5 m spatial resolution. It has three telescopes for forward, nadir and backward views enabling us to generate DEM with accuracy sufficient for 1/25,000 scale maps. Nadir, forward and backward views are used to achieve along-track stereoscopic image. The nadir-looking telescope provides a swath of 70 km width, each of the forward and backward looking telescopes provides a swath of 35 km. The forward and backward telescopes are inclined by ± 24 º from nadir to realize B/H (base to height ratio) of one and 0.5 for nadir and backward at an orbital altitude of 692 km (Jaxa, 2006a).

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ASTER on board of Terra spacecraft is multi spectral optical sensor that was launched on December 1999. ASTER sensor has 14 spectral bands covering visible to thermal infrared bands. All spectral bands of ASTER are divided into three radiometers: Visible Near Infrared (VNIR), Shortwave Infrared (SWIR) and Thermal Infrared (TIR) (ERSDAC, 2003). VNIR has two near infra red bands which have similar wavelengths, those are 3n (nadir looking) and 3b (backward looking). The 3b band is used to achieve the backward looking, with setting angle between the backward looking and the nadir looking is design to be 27,6° (Ersdac, 2002). Nadir and backward looking of AVNIR are used to obtain along-track stereoscopic data to generate DEM and provide B/H equals to 0.6.

Some researchers have reported the DEM accuracy generated from ASTER and PRISM as listed in Table 1. The DEM accuracy of ASTER is varied from 7 to 50 meters depend on topography condition, land cover of observed area and generation method. DEM from PRISM shows better accuracy than DEM from ASTER. The accuracy reaches 3-6 meter due to higher spatial resolution and triplet views of PRISM stereoscopic data. Although the DEM generation and accuracy evaluation have been done by some scientists, those activities (especially for PRISM ALOS) are still rare conducted in Indonesia which has large variation of topography condition. This paper describes DEM generation from stereoscopic data of PRISM and ASTER optical sensors using image matching and collinear model based on Orthobase-pro software. The accuracy evaluation of each DEM is conducted by comparing the generated DEMs with high accuracy of 30 m spatial resolution of SRTM X-C band.

Table 1. The accuracy of ASTER and PRISM DEM.

| Satellite sensor | Reference | Accuracy (m) |
|---|---|---|
| ASTER | Lang & Welch (1999) | 10 – 50 m |
| ASTER | Toutin & Cheng (2001) | 7.9 m |
| ASTER | Hirano et al. (2002) | 7 – 15 m |
| ASTER | Goncalves & Oliveira (2004) | 9 - 11 m<br>Less vegetation |
| PRISM ALOS | Chen T. et al. (2004) | < 3 m (93%) |
| SRTM X- band | Gesch D. (2005) | 3 – 5 m |
| SRTM X and C- band | Yastikh et al. (2006) | 5-6 -9.6 m |
| PRISM ALOS | Jaxa (2006b) | < 6.5 m |
| PRISM ALOS | Bignone & Umakawa (2008) | 2 – 5 m |
| PRISM ALOS | Schneider et al. (2008) | 4 m |

## 2. Research Method

The flowchart of DEM generation is shown in Figure 1. This study used stereoscopic data (Nadir-Backward, B/H=0.5) PRISM level 1B1 with 2.5 m spatial resolution from Japan Aerospace Exploration Agency (JAXA), stereoscopic data (Nadir-Backward, B/H=0.6) ASTER level 1a with 15 m spatial resolution, SRTM DEM X-C band from German Aerospace Center (DLR) with 30 m spatial resolution, and Landsat 7 ETM orthoimage with 15 m spatial resolution (fused with panchromatic band). SRTM X-C band is fused data between 30 m spatial resolution of SRTM X-band and 90 m spatial resolution SRTM C-band. It is used as reference DEM due to its high vertical accuracy as reported in some publications as listed in Table 1.

The study areas are located in Bogor (West Java) and Bengkulu (Bengkulu Province) as shown in Figure 2. Bogor is a mountainous area with elevation reaching

850 m above mean sea level, whereas Bengkulu is located in coastal area with variation of elevation from relatively flat in the coastal area up to high elevation in the mountainous area (around 800 m). Pre-processing was started by cropping the interest area of clear cloud cover. De-striping process was needed for ASTER stereo level 1a data due to striping distortion that still existed in the stereo images. Then both images were rotated 270 degrees clockwise, this process is conducted to make stereoscopic parallax happened along X axis or across track paralax. The next processes were done using Orthobase-Pro software.

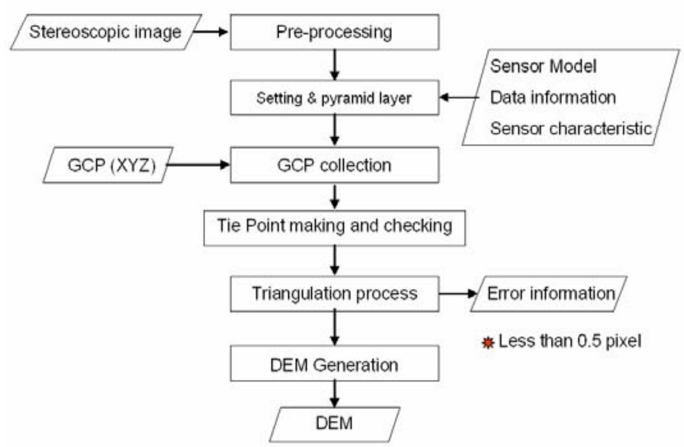



Figure 1. Flowchart of DEM generation process.

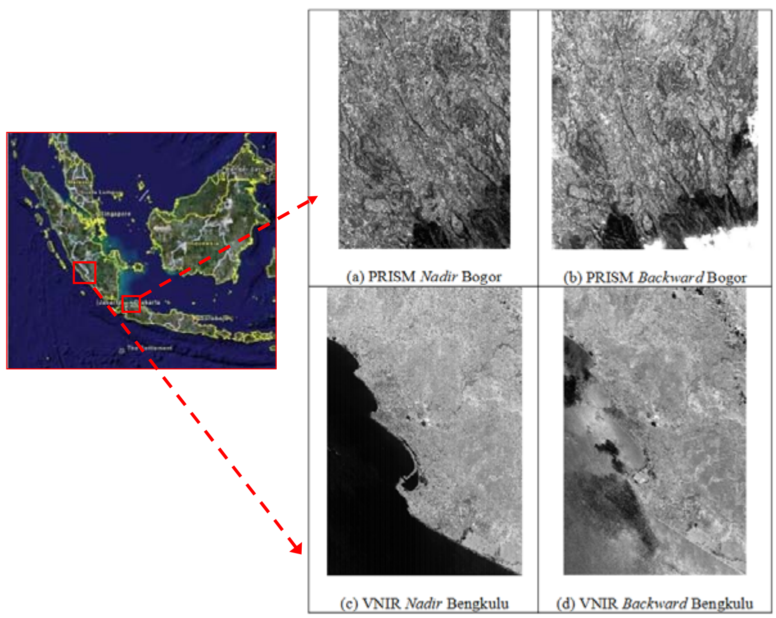



Figure 2. Study area (Bogor and Bengkulu) and Stereo data for PRISM-ALOS (a-b), VNIR-ASTER (c-d).

The initial setting was done for selecting appropriate sensor model i.e. Pushbroom sensor Model, inserting sensor and data characteristic such as focal length, incidence angle, pointing angle, sensor column, pixel size and ground resolution obtained from ancillary data and satellite characteristic references. The next step was to build pyramid layer by making four levels of stereo images (master, and target images) as shown in Figure 3.

Stereo images in level 1 has full resolution, level 2 has 1/2, level 3 has 1/4 and level 4 has 1/8 of the original image resolution. In the image matching process, correlation of master and target images will be done gradually from level 4 (the lowest resolution) until reaching level 1 (the original resolution). By doing the pyramid layer, the matching process will be faster and the correlation of master and target images becomes higher.

Control Points (CPs) XYZ were collected using Landsat-7 ETM orthoimage for XY and SRTM X-C band for Z references. This study used 13 CPs initially for both PRISM and ASTER which were well distributed on whole images. Based on the initial CP, transformation equation were built and then it was used to determine around 50-60 Tie Points (TPs) automatically.

In case of ASTER stereoscopic images, the generated TPs must be corrected and then converted to become CPs. The process which starts with 13 CP but they were added by the corrected TP incrementally around 10 corrected TP each addition, and for each addition the error is evaluated using eq. (3). After reaching CP number more than 40 the errors start to be stable and small, and finally around 60 CP is selected with error shown in Figure 4 and Table 5. However in term of PRISM only the initial 13 CPs were used to achieve error (Table 4) which almost the same as previous research results as shown in Table 1.

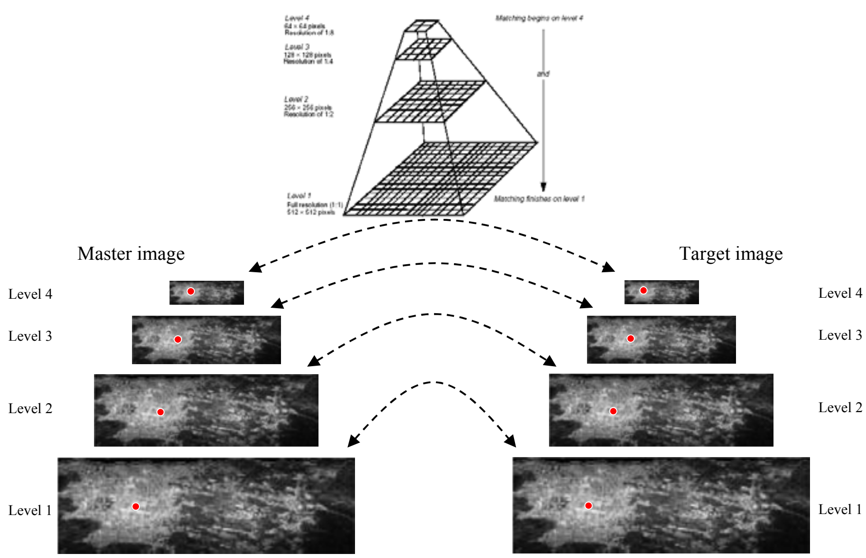



Figure 3. Pyramid layer of four levels of images (Leica Geosystems, 2002).

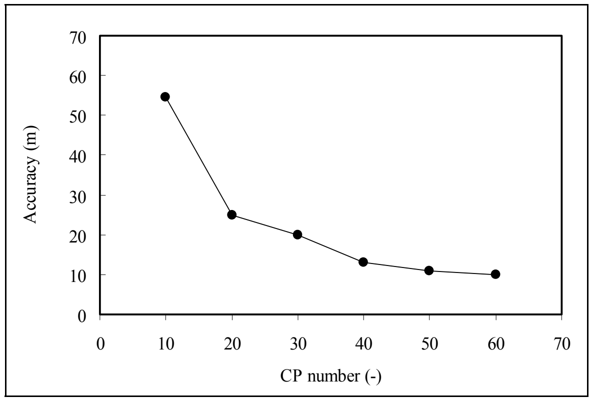



Figure 4. Correlation between number of CPs and accuracy of DEM from ASTER stereo data.

Subsequently, the triangulation process using collinear model is performed to establish relation among xy points on image with XYZ coordinates on the earth surface and also the sensor characteristics. In the triangulation process, some parameters (such as earth curvature, iteration, and weighting point) must be adjusted to obtain correlation with error less than 0.5 pixel.

Several sources of error in generating DEM using satellite images (Ono, 2005) are tie point error, roll (no effect on along track system), pitch, yaw and satellite altitude error. Beside the tie point errors the remaining sources of errors are caused by the attitude of the platform in, this case is the satellite, and those sources of error will not be discussed in this study. The error caused by the inaccuracy of tie point is shown below.

$$\text{Error (prediction)} = \text{Tie Point Error}/(B/H) \quad (1)$$

As shown in previous paragraph, all tie points which subsequently assigned as CP have less than 0.5 pixel displacements or errors. More precisely they are 0.2 pixel for PRISM and 0.3 pixel for ASTER. Using pixel sizes and B/H of both sensors from equation (1), the predicted errors more precisely the predicted lowest achievable error produced by PRISM is equal to 1.0 m and the one produced by ASTER is equal to 7.5 m.

The displacements or errors of tie points in equation (1) represent overall or average accuracy which could only be used after their numbers satisfy the minimum requirement of the transformation functions of triangulation shown in Figure 1. As also known in any statistical estimation the larger the number of sample points in this case the tie points the better the estimate of the transformation function assuming that the error of tie points are small. From the predicted errors mentioned above it could be predicted that for the same quality and numbers of tie points the DEM errors produced from PRISM will always be less than from ASTER. Furthermore to achieve comparable errors from both sensors, assuming the quality of the tie points are the same, the number of tie point required for PRISM will be much less than for ASTER.

The practical meaning of equation (1) is that the accuracy of the DEM depends on the accuracy of the parallax which depends on the accuracy of transformation which depends subsequently on accuracy of tie points. The upper limit of accuracy of tie points is constrained by the pixel size. Therefore the upper achievable limit of the accuracy of DEM is constrained by pixel size. As discuss before the experiments show that the number of tie points or CP for PRISM is only 13 whereas for ASTER is around 60 points.

The last step was image matching between master and target images to obtain relief displacement (parallax). This technique correlates an area or a pixel in master image with the same area or pixel in the target image based on grey value similarity of pixel. It is assumed that the same area or pixel on the stereo image has the higher coefficient correlation shown by equation (2) than other areas or pixels (Leica Geosystems, 2002). Finally, the parallax was used to calculate elevation of each pixel using the developed formulation from the triangulation process shown in Figure 1.

$$\rho = \frac{\sum_{i,j}[g_1(c_1,r_1)-\bar{g}_1][g_2(c_2,r_2)-\bar{g}_2]}{\sqrt{\sum_{i,j}[g_1(c_1,r_1)-\bar{g}_1]^2\sum_{i,j}[g_2(c_2,r_2)-\bar{g}_2]^2}} \qquad (2)$$

with,

$$\bar{g}_1 = \frac{1}{n}\sum_{i,j} g_1(c_1,r_1) \qquad \bar{g}_2 = \frac{1}{n}\sum_{i,j} g_2(c_2,r_2)$$

where,

$\rho$ = Coefficient correlation
$g(c,r)$ = Grey value of pixel (c,r)
$c_1,r_1$ = Pixel coordinate of master image
$c_2,r_2$ = Pixel coordinate of Target image
n = Total pixel number in the window

The accuracies of DEM generated from PRISM and ASTER stereoscopic images were evaluated by comparing height values of each DEM with reference DEM. Transect lines were drawn along the DEM images, then height distribution of each transect lines was compared to that of reference DEM. Finally, RMSE of eq. (3) of height difference between each DEM images and reference DEM was statistically calculated and analyzed (Albert K.W.Y., 2003).

$$\mathrm{RMSE} = \sqrt{\frac{E^2}{n}} \qquad (3)$$

where,

$$E = e_1^2 + e_2^2 + e_3^2 + \ldots e_n^2$$

RMSE = Error/Accuracy
e = Height difference = $E_{reference} - E_{sample}$
n = Total number of sample

## 3. Results and Discussion

### 3.1. DEM Generation from PRISM and ASTER Stereoscopic Data

The generated DEMs are shown in Figure 5 and Figure 6. Color gradation from pink, blue to red color shows the increase of elevation. Visual observation and statistical analysis (Table 2 and 3) were carried out to assess the quality of generated DEM. Visual observations were done by comparing the elevation pattern of generated DEM with its reference DEM (SRTM X-C band) in some areas; catchments area, hill or mountainous area, and different land cover area. DEM from stereoscopic images of PRISM and ASTER show relatively similar elevation pattern and range value comparing to reference DEM. The minimum, maximum and mean values of both generated DEM are shown in Table 2 and 3 whereas the differences among those values with the ones of DEM SRTM are shown in Table 4 and 5.

Bogor has high mean value which represents mountainous areas, whereas Bengkulu has lower mean value which represents low elevation area. Although ASTER DEM has higher spatial resolution (15m) than SRTM, but it does not have smooth elevation pattern as well as reference DEM. On other hand, PRISM can produce DEM with high spatial resolution (2.5m) and smoother elevation pattern compare to reference DEM.

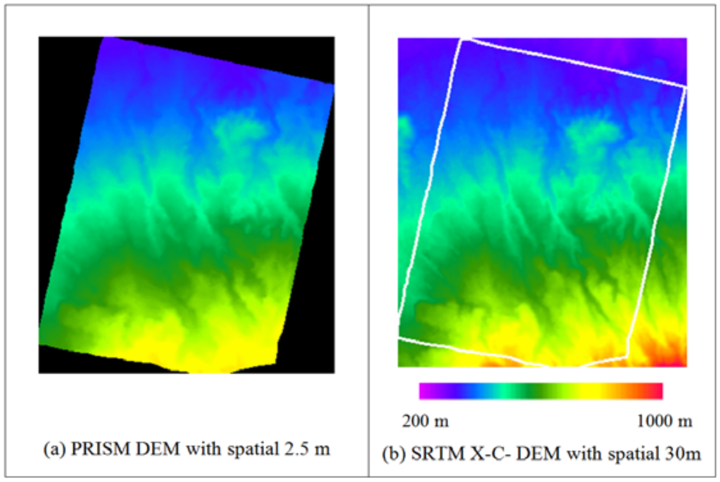



Figure 5. Comparison of SRTM X-C band with DEM from PRISM of Bogor area.

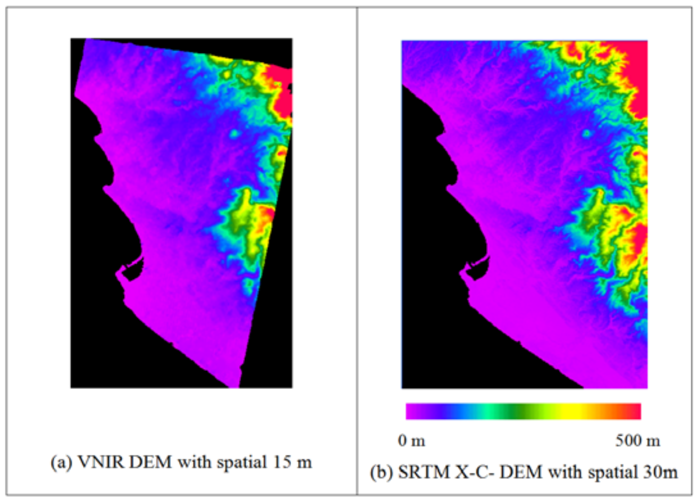



Figure 6. Comparison of SRTM X-C band with DEM from AVNIR-ASTER of Bengkulu area.

Table 2. Statistical values of DEM from PRISM in Bogor area.

| **Full image** | **Min Value (m)** | **Max Value (m)** | **Mean Value (m)** |
|---|---|---|---|
| DEM (PRISM) | 306 | 834 | 518 |
| SRTM DEM | 295 | 854 | 515 |

Table 3. Statistical values of DEM from ASTER in Bengkulu area.

| **Full image** | **Min Value (m)** | **Max Value (m)** | **Mean Value (m)** |
|---|---|---|---|
| DEM (ASTER) | -15 | 815 | 81 |
| SRTM DEM | -13 | 963 | 79 |

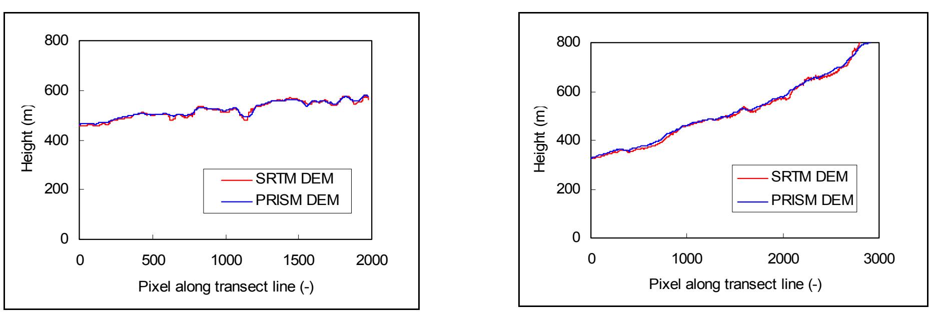
### 3.2. Accuracy Analysis of Generated DEMs

Evaluation of DEM accuracy for each DEM was done by comparing height distribution along transect lines on DEM images and statistical value analysis. Figure 7 and 8 shows comparison of height distribution between generated DEMs and reference DEM along the transect line. The transect lines are made by drawing horizontal, vertical and diagonal line along DEM image. Area of DEM from PRISM (Bogor) is located in mountainside where height distribution does not have a lot of variations but increases gradually toward west or south. It is different with area of DEM from ASTER (Bengkulu) which is divided into coastal area in east side and mountainous area in west side. Height distribution of DEM from ASTER shows more variations from relatively flat until elevation achieves around 800 m.

The height distribution of DEM from PRISM is almost similar with that of reference DEM both in distribution pattern and elevation values in all transect lines. Height difference between DEM from PRISM and reference DEM were obtained by subtraction process, and then minimum, maximum, mean and RMSE value were calculated shown in Table 4. RMSE values of height differences along horizontal for around 2000 pixels and diagonal for around 3000 pixels transect lines are 5.9 m and 6.2 m respectively, and 6.5 m for the whole DEM image area calculated for around 6.2 million pixels.

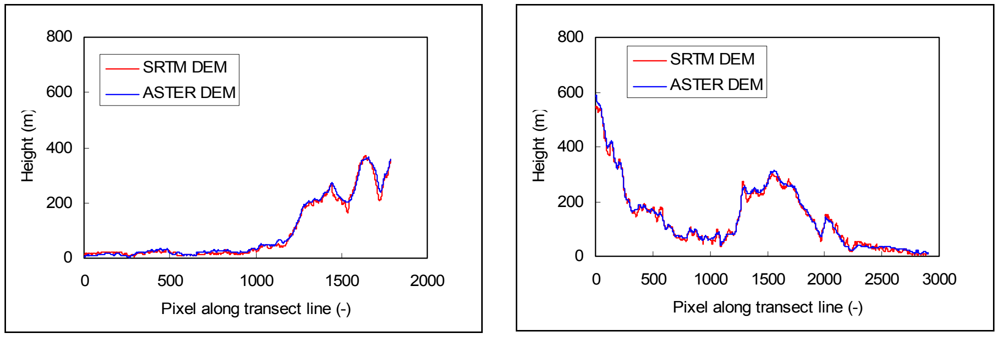
On other hand, the height distribution of DEM from ASTER along vertical and horizontal transect line are similar with its reference DEM in distribution pattern but with small different in elevation value. The RMSE values of height differences along horizontal for around 1,800 pixels and vertical for around 2,900 pixels transect lines are 10.2 m and 10.7 m respectively, and 10.2 m for the whole DEM image area calculated for around 5,5 million pixels.

By comparing the result in Table 4 and Table 5, it is shown that RMSE of DEM from PRISM is better although uses only 13 CP than DEM from ASTER which uses around 60 CP in the study area. This RMSE result is confirming the predicted error given by equation (1) particularly that the accuracy is dependent on pixel size We had already observed that the more CP used in the process the higher the accuracy of generated DEM (Trisakti, 2006). Therefore the accuracy of PRISM could be increased by adding more CP as input in CP collection.




(a) Height distribution along Horizontal transect line. (b) Height distribution along diagonal transect line.

Figure 7. Comparison of height distribution between PRISM DEM and SRTM.




(a) Height distribution along Horizontal transect line. (b) Height distribution along vertical transect line.

Figure 8. Comparison of height distribution between ASTER DEM and SRTM.

Table 4. Statistical values of height differences of PRISM DEM and SRTM.

| PRISM-SRTM | Min Val (m) | Max Val (m) | Mean Val (m) | RMSE (m) |
|---|---|---|---|---|
| Along horizontal transect | -26 | 19 | 2.7 | 5.9 |
| Along diagonal transect | -40 | 39 | 3.3 | 6.2 |
| Whole image (6.2 million pixel) | -41 | 43 | 2.0 | 6.5 |

Table 5. Statistical values of height differences of ASTER DEM and SRTM.

| ASTER-SRTM | Min Val (m) | Max Val (m) | Mean Val (m) | RMSE (m) |
|---|---|---|---|---|
| Along horizontal transect | -20 | 46 | 4.2 | 10.2 |
| Along Vertical transect | -31 | 43 | 3.7 | 10.7 |
| Whole image (5.5 million pixel) | -112 | 108 | 3.0 | 10.2 |

## 4. Conclusion

This study results indicated that:

- The stereoscopic data of PRISM and ASTER can be used to generate DEM with high spatial resolution, 15 m and 2.5 m respectively. The higher spatial resolutions are improvements to the reference DEM.
- The visual observation result showed that PRISM DEM had smoother elevation pattern compared to reference DEM which was not observed in ASTER DEM. These were due to their spatial resolutions.
- The RMSE of DEM using PRISM and ASTER theoretically depend on the size of their pixel therefore for the same numbers and quality of CP, RMSE of DEM using PRISM will always better than DEM using ASTER.
- The experiments showed that RMSE of height difference between DEM using PRISM and reference DEM was 6.5 m by using only 13 CP with accuracy of 0.2 pixel.
- The experiments also showed that RMSE of height difference between DEM using ASTER and reference DEM was 10.2 m by using around 60 CP with accuracy of 0.3 pixel.
- The abovementioned two experiment results confirmed the theory that the lowest achievable error of DEM produced were dependent on pixel sizes.

## 5. Acknowledgements

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