International Journal of Remote Sensing and Earth Sciences Vol. 8: 41-48 (2011) © IReSES

DEM GENERATION FROM STEREO ALOS PRISM AND ITS QUALITY IMPROVEMENT

Bambang Trisakti and Atriyon Julzarika

Abstract. Digital elevation mode (DEM) is important data for supporting many activities. One of DEM generation methods is photogrametry of optical stereo data based on image matching and collinear correlation. The problem of DEM from optical stereo data is bullseye due to low contrast in relatively flat area and cloud cover. The research purpose is to generate DEM from ALOS PRISM stereo data level 1B2R and improve the quality of the DEM. DEM was generated using Leica Photogrametry Suite (LPS) software. The study area is located in Sragen district and its vicinity. The process needed three dimension of Ground Control Point (GCP) XYZ, as input data for collinear correlation. Ground measurement was conducted using differential GPS to collect 30 GCPs that used for input (21 GCPs) and for accuracy evaluation (9 GCPs). The generated DEM has good detail (10 m), but it has bullseye which mostly occurred in relatively flat area. The quality improvement was carried out by combining the DEM with SRTM DEM (30 m) using DEM fusion method. Both DEMs were processed for geoids correction (EGM 2008), co-registration and histogram normalization. The fusion method was conducted by considering height error map (HEM) of each DEM. The quality of fused DEM was evaluated by comparing HEM, the number of bullseye, and vertical accuracy before and after the fusion. The result shows that DEM fusion can preserve detail information of the DEM and significantly reduce the bullseye (decreasing more than 66% of bullseye). It also shows the improvement (from 7.6 m to 7.3 m) of vertical accuracy.

Keywords: *Digital Elevation model, Optical stereo data, ALOS PRISM, DEM fusion, Bullseye*

1. Introduction

Digital elevation model (DEM) is very important data for supporting many activities, such as data correction, contour mapping, and disaster mitigation. DEM can be generated using photogrametry of optical stereo data. Recently, many optical satellite sensors with high spatial resolution have been lunched. Some of them have capabillity to record stereo data (such as: ASTER, ALOS, Cartosat and SPOT), which can be applied to generate high accuracy of DEM.

ALOS (Advanced Land Observation Satellite) is a Japanese satellite, was launched on January 24th 2006, and is equipped with PRISM, AVNIR and PALSAR sensors. PRISM (The Panchromatic Remote-Sensing Instrument for Stereo Mapping) 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 user to generate DEM with sufficient accuracy for 1/25,000 scale maps (JAXA, 2006a). The nadir view telescope provides a swath of 70 km width, and the forward and backward view telescopes provide a swath of 35 km. The forward and backward view telescopes are inclined by ± 24 º from nadir to realize a base to height ratio of one at an orbital altitude of 692 km.

DEM generation from ALOS PRISM stereo data and accuracy analysis of the generated DEM have been studied by several researchers (Table 1**)**. Bignone and Umakawa (2008) evaluated the accuracy of DEM from ALOS PRISM for plain and mountaineous area in Kanagawa Prefecture (JAPAN), where the vertical accuracy has range from 2 m (plain area) to 5 m (mountaineous area). Wolff and Gruen (2007) have assessed the accuracy of DEM in different land use characteristic, and found that the accuracy of DEM was 2-3 pixels in sub-area, 2 pixels in open land, and 5 pixels in a tree-coverage area. In the previous study (Trisakti et al., 2010), DEMs were generated from ALOS using Leica Photogrametry Suite (LPS) software in 2 different topography conditions, mountaineous area and mixing areas between mountaineous and flat areas. The result was consistent with all research in Table 1, which the accuracy of DEM is about 3.5 - 6.5 m.

Although DEM from ALOS PRISM stereo images has good accuracy (Table 1) and high spatial resolution (2.5-10 m), it still has a problem with the quality. There is bullseye due to the effect of haze, less of Ground Control Point (GCP) and low contrast of the stereo images in the DEM generation process. Bullseye is a pixel which has high or low pixel value compared to its neighbor, it can be detected as a spire (the highest value compared to the surrounding pixels) or pit (the lowest value compared the surrounding pixels) as shown in Figure 1. The existing of bullseye causes low quality pixel (bad pixel) in DEM image. Increasing the number of bullseyes

Scientist in Remote Sensing Application Center, Indonesia National Institute of Aeronautics and Space (LAPAN)

means increasing the number of bad pixels, and decreasing of the DEM overal accuracy.

Bullseye removal methods have been studied by some researchers. Interpolation models, such as kriging and Inverse Distance Weighting (Azpurua and Ramos, 2010) are the general method for bullseyes removal. The interpolation process results in a smooth surface, which reduce the number of pit and spare in the DEM image. Hoja et al. (2006) reported that fusion or integration between 2 DEMs (DEM from SPOT-5 stereo data and Shuttle Radar Topography Mission (SRTM)) can reduce bullseye and in turn increase the accuracy of the DEM. Both fusion and integration methods used height error map (HEM) of each DEM to generate the new DEM with less bullseyes and higher accuracy compared to the original DEMs. Integration method can produce higher vertical accuracy of the new DEM compared to fusion method, but fusion method is simpler and faster in process (Trisakti et al., 2011).

Table 1. The accuracy of DEM ALOS

Year	Satellite sensor	Author	Accuracy (m)
2006b	ALOS PRISM	JAXA	< 6.5 m
2008	ALOS PRISM	Bignone & Umakawa	2 – 5 m
2007	ALOS PRISM	Wolff and Gruen	2-5 pixels
2010	ALOS PRISM	Trisakti et al.	3.5 – 6.5 m

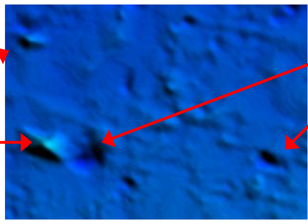


Figure 1. Spire and Pit in DEM data

This research has 2 purposes, those are the generation of DEM from ALOS PRISM using field measurement GCPs by differential GPS, and the reduction of the bullseye of ALOS PRISM DEM using DEM fusion method to improve the DEM quality. DEM fusion between DEM from ALOS PRISM and SRTM is conducted by considering the Height Error Map. The quality of fused DEM was evaluated by comparing bullseye and absolute vertical accuracy before and after the fusion process.

2. Methodology

2.1. Study area

The Study area is Sragen in the Central Java province, shown by blue box in Figure 2. According to topography condition based on SRTM DEM, the study area has montainous area ranged from 50 m to more than 500 m in height.

2.2. Datasets

The DEM is generated using stereo pair of ALOS PRISM (Nadir and Backward), acquisited in 2007, level 1B2R with 2.5 m spatial resolution. Three dimensional of field coordinate XYZ was measured using differential GPS in September 2010, and used as input (21 GCPs) and for accuracy evaluation (9 GCPs). The quality of improvement was carried out by combining the generated DEM from ALOS PRISM with SRTM DEM (30 m spatial resolution).

2.3. Method

The method of this research is divided into 3 stages: 1) DEM generation and 2) DEM fusion, and 3) quality evaluation. In the first stage (Figure 3), the PRISM nadir image was divided into 20 area, and then each area was identified to determine location of GCPs (Figure 4). In this research, DEM from PRIMS stereo data was generated using Leica Photogrametry Suite software. The initial setting was done for selecting appropriate sensor model (Pushbroom Sensor Model), inserting sensor and data characteristic. The collected GCPs were used as input data in the process. Based on 21 GCPs, transformation equation were built and then it was used to determine around 50-60 Tie Points (TPs) automatically. Later, the generated TPs were corrected and converted to become Control Point (CPs). Finally, the total number of CPs that was used in the DEM generation process becomes 77 CPs. The error becomes stable and small, if it uses CPs more than 60 (Trisakti et al., 2009)

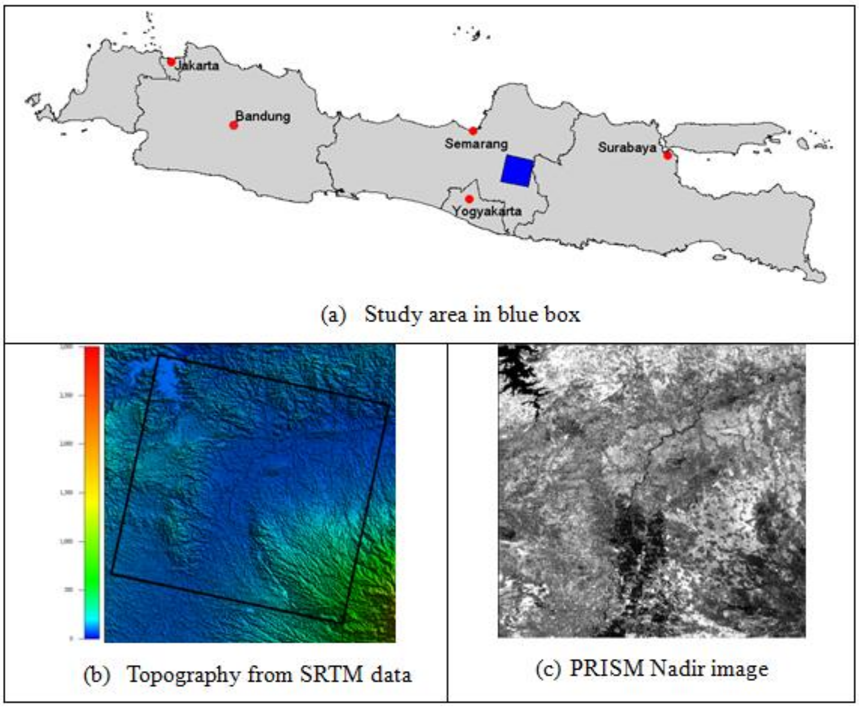


Figure 2. Study area of this research

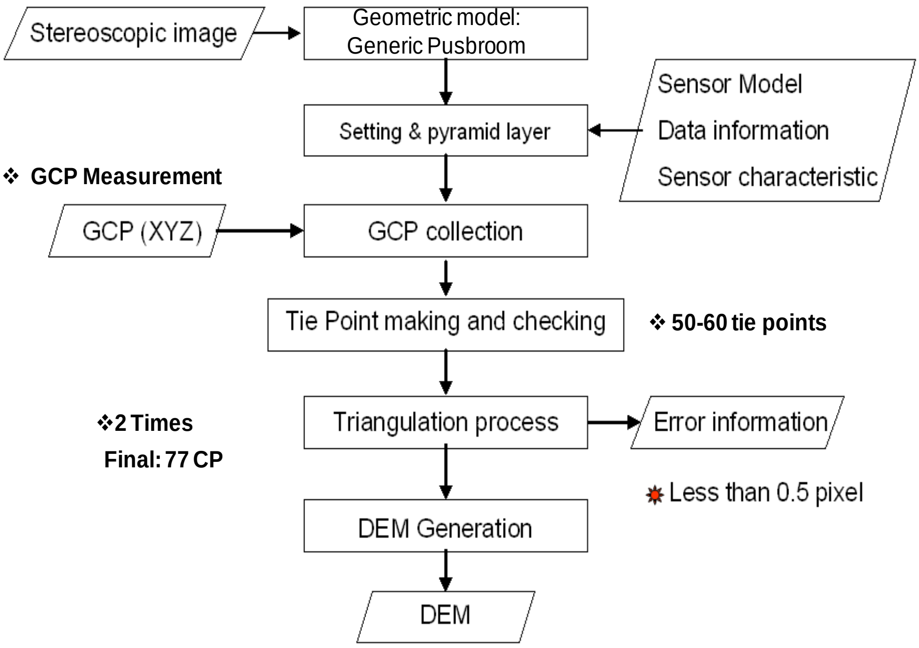


Figure 3. Flowchart of DEM generation

The triangulation process using collinear model was performed to establish relation among xy points on image (pixel coordinate), XYZ coordinates on the earth surface (ground coordinate), and sensor characteristics. Then, the image matching between master and target images was conducted to obtain relief displacement (parallax). The parallax was used to calculate elevation of each pixel using developed formulation from triangulation process. DEM from ALOS PRISM can be produced for 2.5 m spatial resolution, but it takes much time for the processing and the surface is still rough. Here, the spatial resolution of DEM product was set to be 10 m to obtain the smooth DEM and faster process.

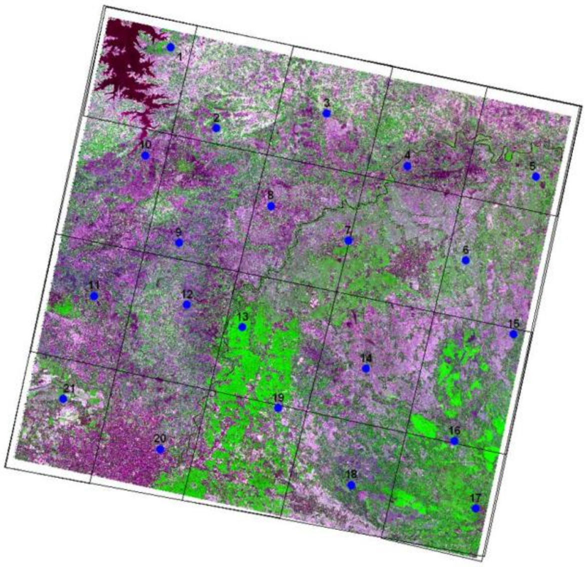


Figure 4. Distribution of 21 GCPs/CPs in Sragen area

In the second stage (Figure 5), standarisation of Elipsoid-Geoid Model 2008 and co-registration between DEM ALOS PRISM and SRTM was conducted to make the same reference and geometric (position) of both DEM. Height normalization was conducted for DEM SRTM using mean value and standard deviation of both DEMs as shown in equation (1).

$$Z_{output} = (SZ_{ALOS}/SZ_{SRTM})(Z_{SRTM}-MZ_{SRTM})+MZ_{ALOS} \quad (1)$$

where,
Z : Height of DEM
SZ : Standard deviation DEM output and Input
MZ: Mean of DEM output and input

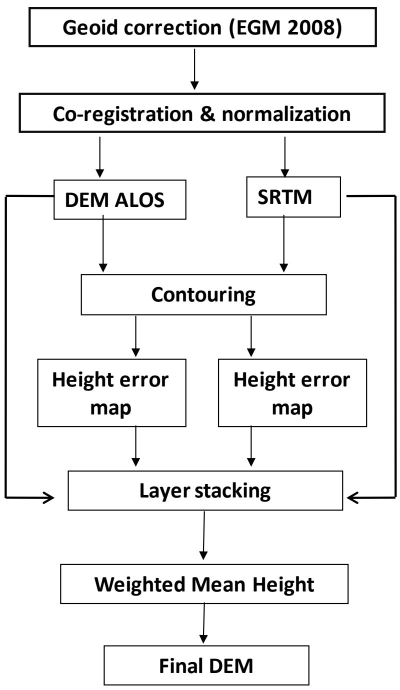


Figure 5. Flowchart of DEM Fusion

HEM of each DEM was generated using Surfer software. HEM shows standard deviation of DEM pixels, High Height Error means large standard deviation of that pixel. First, each DEM was converted to contour lines with 5 m interval, then the contours were converted to height points XYZ. Finally, the height points were interpolated using Co-kriging interpolation method to produce new DEM and HEM. All HEMs and DEMs were integrated into one set data, and then the algorithm in equation (2) of DEM fusion was applied to fuse between DEM from ALOS and DEM SRTM.

$$h_{out} = \frac{\sum h_i \cdot p_i}{\sum p_i} \quad (2)$$

where,
$p_i = 1/a_i$, $a_i > 0$
h_i : DEM value (i=1,2)
a_i : DEM accuracy, DEM error (i=1,2)

Quality of DEM fusion was evaluated by comparing the number of bullseye and the vertical accuracy before and after DEM fusion. Pit/spire was detected using window 5 X 5 as shown in Figure 6. Pixel C is identified as pit/spire if it is fulfilled 2 conditions,

1) C must be higher/lower compared to all pixels in the window and
2) C must be higher/lower compared to 8 pixels (pixel X) by the value of pit/spire height which can be adjusted in the input process.

In the initial evaluation of pit/spire detection, the number of pit/spire increased as the value of pit/spire height decreased. When the pit/spire height was around 3 times standard deviation (3σ) the location of pits/spires were relatively same as the location of bullseyes from the visual observation. The pit/spire height was set to be 3σ.

X		X		X
X		C		X
X		X		X

Figure 6. C with window 5 X 5 for pit/spire detection

On the other hand, the vertical accuracy was evaluated using 9 GCPs from the ground measurement. All GCPs were well distributed in whole DEM image. The accuracy was calculated based on the adjustment computation method (Julzarika, 2010).

3. Result and Discussion

Figure 7 shows the generated DEM from ALOS PRISM and the DEM quality of Sragen area using 21 GCPs. This DEM has 10 m spatial resolution, and is shown in 3 dimension view with elevation range from about 50 m (green color) until more than 500 m (red color) in south east part (mountaineous area). The accuracy of the generated DEMs against total of 77 control points (21 GCPs/CPs and 56 tie points) used in DEM generation process is shown in Table 2. The vertical accuracy (Root Mean Square Error) is 3.6 m and the horisontal accuray (Absolute Linear Error 90) is 5.8 m.

The mass point quality of DEM is divided into 5 classes, those are: Excellent (green), Good (blue), Fair (yellow), Isolated (brown) and Suspicious (red). Excellent, Good and Fair have pixel quality with confidence level more than 50%, and cover more than 86% of DEM's pixels. On the other hand, Isolated and Suspicious have pixel quality with confidence level less than 50%, and cover only 14% of DEM's pixel. Isolated and Suspicious pixel are called "bull eye", and they are distributed in whole DEM image especially in flat area. So, it needs post processing (bullseye correction) to improve the quality of DEM from ALOS PRISM.

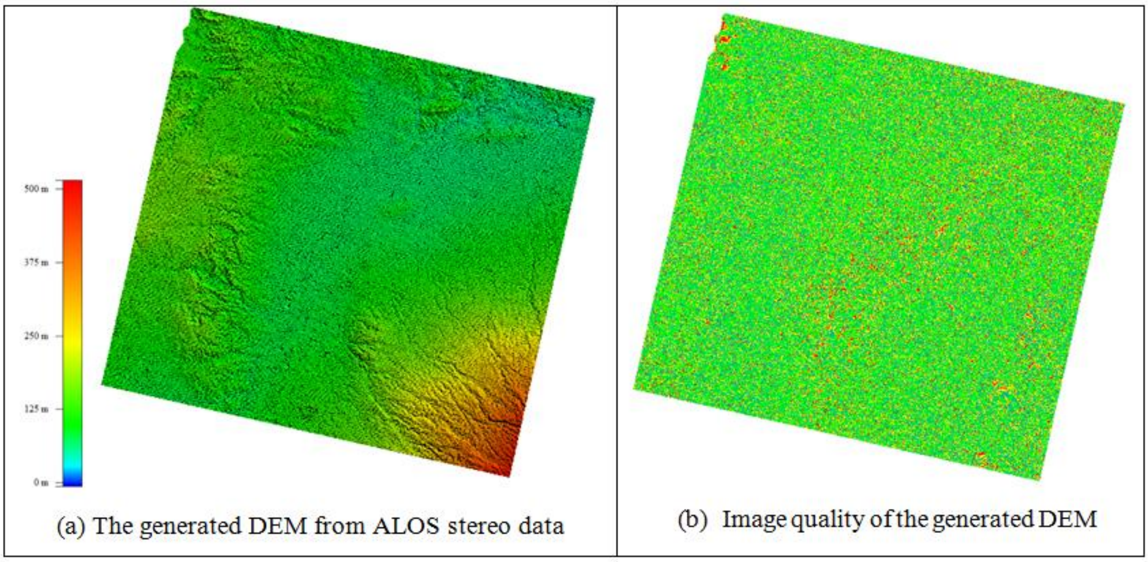


Figure 7. The generated DEM from ALOS PRISM stereo data (a) and the mass point quality of the generated DEM (b) using GCPs from field measurement

Table 2. The accuracy report of the generated DEM (using GCP from field measurement) against total of 77 control points

Minimum, Maximum Error:	-9.9 m, 11.8 m
Mean Error:	-0.4 m
Mean Absolute Error:	2.7 m
Root Mean Square Error (RMSE):	3.6 m
Absolute Linear Error 90 (LE90):	5.8 m

Before carrying out the DEM fusion process, both DEM must have same position and relatively same height range. The both DEM (from ALOS PRISM and SRTM) were processed for geoid correction, co-registration and height normalization (Figure 8**)**. As seen in Figure 8, DEM from ALOS PRISM has more detail information compared to DEM SRTM (river line can be clearly detected in DEM from ALOS PRISM), but DEM from ALOS PRISM has many bullseye. The bullseye are distributed in center part of image which has relatively flat area. On the other hand, DEM SRTM has lower detail information, but has less bullseye in relatively flat area. The advantages of each DEMs are expected to be able to be fused for getting better DEM. After the correction, both DEM have relatively the same pattern of height distribution which ranges 0 – 420 m. It means that height difference between two DEMs has been reduced and fusion process can be started.

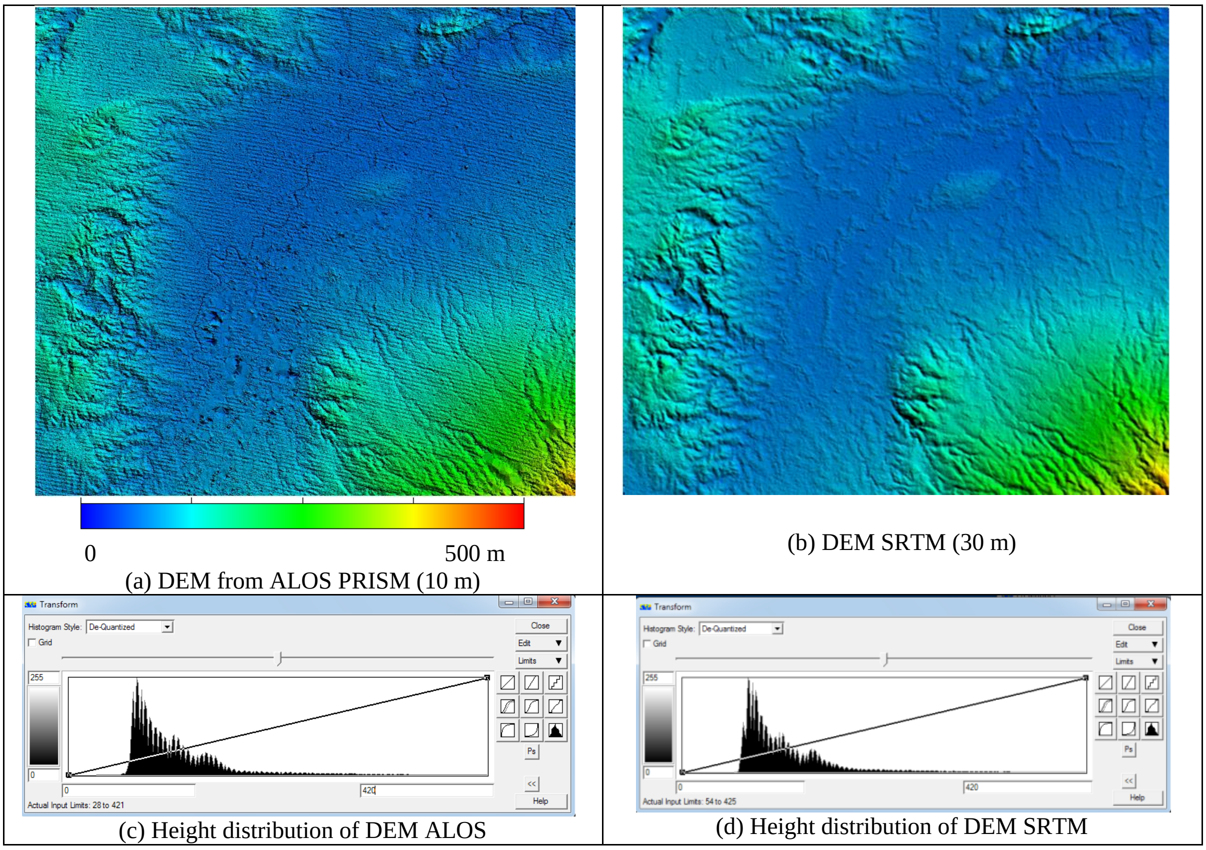
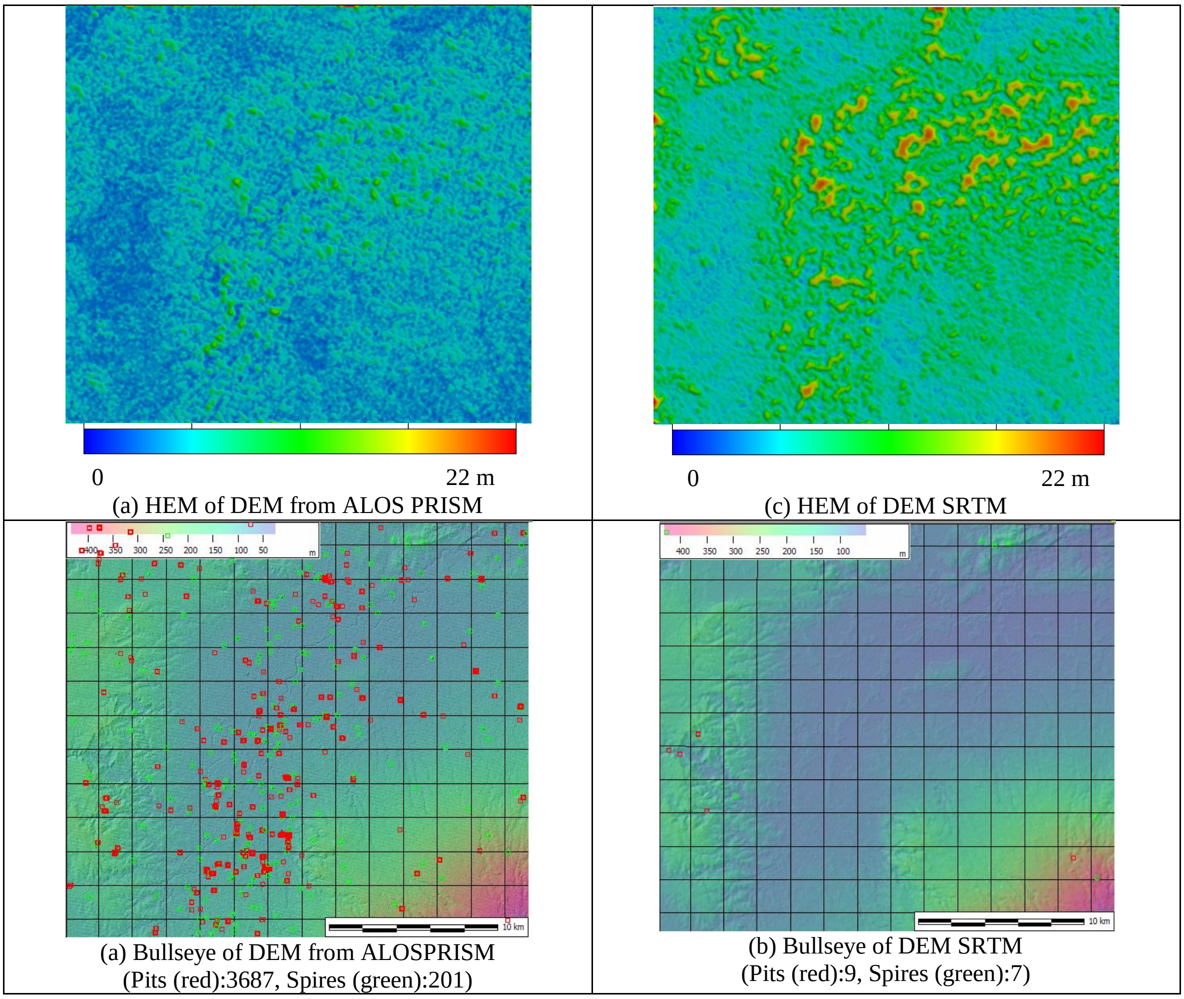


Figure 8. DEM from ALOS PRISM and DEM SRTM after correction

The strategy of DEM fusion is refering to the method strategy developed by Hoja et al. (2006). They fused DEM generated SPOT 5 and DEM SRTM by using HEM from both DEMs. Figure 9 shows HEM and number of pit/spire detected in DEM from ALOS PRISM and DEM SRTM. Pit and spire were detected using specific pit/spire height of 12m. The value is related to 3σ of DEM from ALOS PRISM (RMSE in Table 2). The results show that DEM from ALOS PRISM has 3888 bullseyes (pit+spire), meanwhile DEM SRTM has only 16 bullseyes. The overall comparison between two DEMs show that although DEM from ALOS PRISM has lower height error, it has very large number of bullseye comparing to DEM SRTM.

Figure 10 depicts the generated DEM fusion with 10 m spatial resolution, HEM and bullseye distribution of the DEM fusion. Evaluation between DEM from ALOS PRISM and DEM fusion shows that DEM fusion still has the same spatial resolution with DEM from ALOS PRISM, and detail information of object (such as river) can be preserved. It is found that there is a little bit reduction of height error (around 3%) in the Height Error Map of DEM fusion. The bullseye detection result shows that the number of bullseye significantly decreases. The number of bullseye of DEM from ALOS PRISM (before DEM fusion) was 3888 bullseyes, but the number of bullseye of DEM fusion decreased to become 1733 bullseyes (Figure 10).



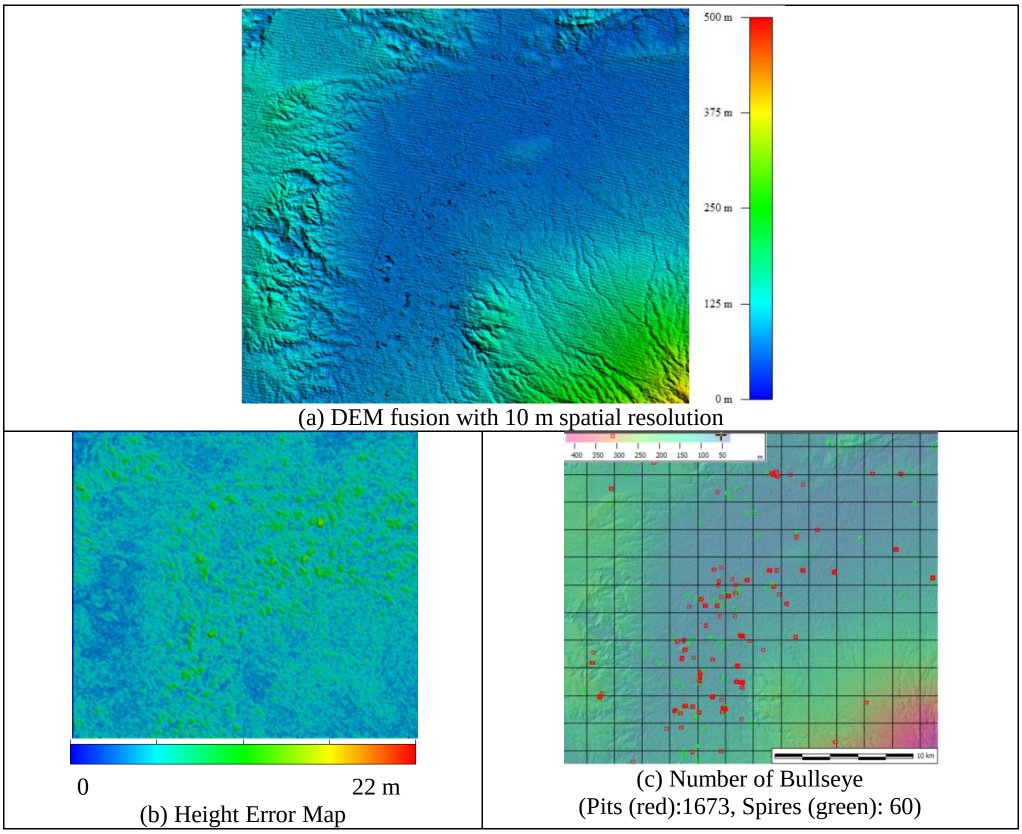
(a) HEM of DEM from ALOS PRISM

(c) HEM of DEM SRTM

(a) Bullseye of DEM from ALOSPRISM (Pits (red):3687, Spires (green):201)

(b) Bullseye of DEM SRTM (Pits (red):9, Spires (green):7)

Figure 9. HEM and Bullseye (Pit and Spire) distribution



(a) DEM fusion with 10 m spatial resolution

(b) Height Error Map

(c) Number of Bullseye (Pits (red):1673, Spires (green): 60)

Figure 10. DEM fusion, Height Error Map, and bullseye of the DEM fusion

Finally, the quality of DEM fusion was evaluated by comparing the number of bullseye and the vertical accuracy before and after DEM fusion. The number of bullseye after DEM fusion decreases to 66% of the original DEM, and the RMSE of DEM fusion decreases from 7.6 m to 7.3 m (vertical accuracy increases). The vertical accuracy is still lower compared to the previous research (Table 1). The difference of vertical accuracy between this research and the previous one is thought to be due to the different method used for the accuracy evaluation, which was the American standard method for the previous, and adjustment computation method for this research. However the difference is not significant, and this result is still consistent with Wolff and Gruen (2007).

4. Summary of Result and Conclusion

DEM was generated from stereoscopic data of ALOS PRISM, and then DEM fusion method was used to reduce the bullseye of the generated DEM. Some results are shown as bellow:

- Detail DEM can be generated using ALOS PRISM stereo data, but it still has bullseye due to some factors in DEM generation process
- DEM fusion still has same spatial resolution with DEM from ALOS PRISM, and detail information of objects can be preserved
- DEM fusion method can significantly reduce the bullseye (decreasing more than 66%) in whole DEM image
- DEM fusion has little bit improvement in vertical accuracy (from 7.6 m to be 7.3 m), but the improvement is not significant. It is considered due to DEM from ALOS PRISM and DEM SRTM have large difference in spatial resolution and HEM. So, it is important to evaluate effect of spatial difference for DEM fusion in the next research.

According to the results, it was concluded that DEM was successfully generated from ALOS PRISM, and the bullseye of DEM could be significantly reduced using DEM fusion method.

5. Acknowledgment

The author thanks to Japan Aerospace Exploration Agency (JAXA) for their ALOS PRISM data providing, and also thanks to reviewers for their important advices and corrections.

6. References

Azpurua, M. and K. Dos Ramos, 2010, A comparison of spatial interpolation methods for estimation of average electromagnetic field magnitude, Progress In Electromagnetics Research M, Vol. 14, 135-145

Bignone, F. and H. Umakawa, 2008, Assessment of ALOS PRISM digital elevation model extraction over Japan, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII, Beijing

Hoja, D., P. Reinartz, and M. Schroeder, 2006, Comparison Of DEM generation and combination methods using high resolution optical stereo imagery and interferometric SAR data, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science, Volume XXXVI, Part 1, Paris, France

JAXA, 2006a, Annual Report 2005, EORC Bulletin, No. 9, March 2006

JAXA, 2006b, The Second ALOS Research Announcement: Calibration and validation, utilization research and scientific research, Earth Observation Research Center Japan Aerospace Exploration Agency, Japan

Julzarika, A., 2010, Geostatistical test using least square adjustment computation to obtain the reduction parameter for DSM to DEM conversion, International Journal Remote Sensing and Earth Sciences, Vol.7

Trisakti, B., I. Carolita, and F.A. Pradana, 2009, Digital Elevation Model from PRISM-ALOS and ASTER stereoscopic data, International Journal of Remote Sensing and Earth Sciences, Vol.6: 29-38

Trisakti, B., G. Winarso, and A. Julzarika, 2010, Utilization of IKONOS image and SRTM as alternative control point reference for ALOS DEM, International Journal Remote Sensing and Earth Sciences, Vol.7

Trisakti, B., 2011, Development of DEM fusion method among DEM SRTM, ALOS PRISM and topography map, Final report of PKPP-Ristek Program, Centre of Remote Sensing Application, LAPAN (In Bahasa)

Wolff, K. and A. Gruen, 2007, DSM generation from early ALOS/PRISM data using SAT-PP, High-Resolution Earth Imaging for Geospatial Information, Proceedings of ISPRS Hanover Workshop, May 29th - June 1st (on CD-ROM).