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UTILIZATION OF IKONOS IMAGE AND SRTM AS ALTERNATIVE CONTROL POINT REFERENCE FOR ALOS DEM GENERATION

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Abstract. Digital Elevation Model (DEM) was generated from Advanced Land Observation Satellite - The Panchromatic Remote-Sensing Instrument for Stereo Mapping (ALOS PRISM) stereo data using image matching and collinear correlation based on Leica Photogrametry Suite (LPS) software. The process needs three dimension of Ground Control Point (GCP) or Control Point (CP) XYZ as input data for collinear correlation to determine exterior orientation coefficient. The main problem of the DEM generation is the difficulty to obtain the accurate field measurement GCP in many areas. Therefore, another alternative CP sources are needed. The aim of this research was to study the possibility of (IKONOS) image and Shuttle Radar Topography Mission (SRTM) X-C band to be used as CP reference for ALOS PRISM DEM generation. The study area was Sragen and Bandung region. The DEM of each study area was generated using 2 methods: generated using field measurement GCPs taken by differential GPS and generated using CPs from IKONOS image (XY coordinat) and SRTM for (Z elevation). The generated DEMs were compared. The accuracy of both DEMs were evaluated using another field measurement GCPs. The result showed that the generated DEM using CPs from IKONOS and SRTM X-C had relatively same height pattern and height distribution along transect line with the DEM using GCPs. The absolute accuracy of the DEM using CPs was about 60% - 80% less accuracy comparing to the DEM using GCPs. This research showed that IKONOS image and SRTM X-C band can be considered as good alternative CP source to generate high accuracy DEM from ALOS PRISM stereo data.

Keywords: *ALOS PRISM, CP, DEM generation, GCP, IKONOS, SRTM*

1. Introduction

DEM is a main source to produce information of land topography. DEM can be generated using some methods, such as: interpolation of height point, interferometry of Synthetic Aparture Radar (SAR), and photogrametry of optical stereo data. Recently, the development of satellite technology, especially for optical sensor, is very fast. Many optical satellite sensors with high spatial resolution have been launched from many countries. Some of them have capabillity to record stereo data (such as: ALOS, Cartosat, SPOT) for producing high accuracy of DEM. According to that reason, nowdays optical stereo data is one of the best choice to be used for generating DEM based on satellite data.

ALOS is a Japanese satellite launched on January 24th 2006. It is equipped by 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.

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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 (JAXA, 2006).

Research activities related to DEM generation from ALOS PRISM stereo data and accuracy analysis of the generated DEM have been published in some papers as shown in Table 1. The DEMs were generated based on image matching and colinear correlation method using some image processing softwares such as: Imagine, PCI and so on. According to those results, the accuracy of DEM generated from ALOS is about 2 - 6.5 m (Tabel 1). We also generated DEM from ALOS stereo data using Orthobase-Pro modul from Imagine software (Trisakti and Pradana, 2007), the accuracy of the generated DEM was about 6.5 m which relatively same with previous research (Table 1). It was also known from the research that the accuracy of the generated DEM was significantly affected by pixel size, data level and accuracy of Ground Control Point or Control Point (GCP/CP) used in the process. In the DEM generation process using Orthobase-Pro, it needs three dimension GCP/CP of XYZ as input data for collinear correlation to determining exterior orientation coefficient. The coefficients will be used to calculate ground space coordinate using space forward intersection technique (Leica Geosystems, 2002). So the higher accuracy of GCP/CP input results the higher accuracy of generated DEM.

The main problem to generate accurate DEM is the difficulty to obtain accurate GCP in the interest area. The accurate GCP can be obtained by field measurement using differential GPS (Global Positioning System). But in reality, the field measurement needs big efforts such as: high cost for going to the location, high cost for preparing the measurement devices and long time for GCP measurement. So, it should be thought another CP reference to fulfil the GCP needs for DEM generation process. Google Earth image or map is commonly used as alternative geo-reference for navigation and also for geometric correction of satellite image, because it is easy and free to be obtained via internet connection. This program can map the earth based on many images (satellite image, airborne image, Globe GIS 3D and so on) superimposed. Satellite images in the program are consist of low spatial resolution image (MODIS), medium spatial resolution image (Landsat and SPOT) and high spatial resolution image (IKONOS, QuickBird). The high spatial resolution image can identify objects accuratelly, so it is suitable to be used as reference to find CP for ALOS PRISM image.

Table 1. The accuracy results of DEM from ALOS stereo data

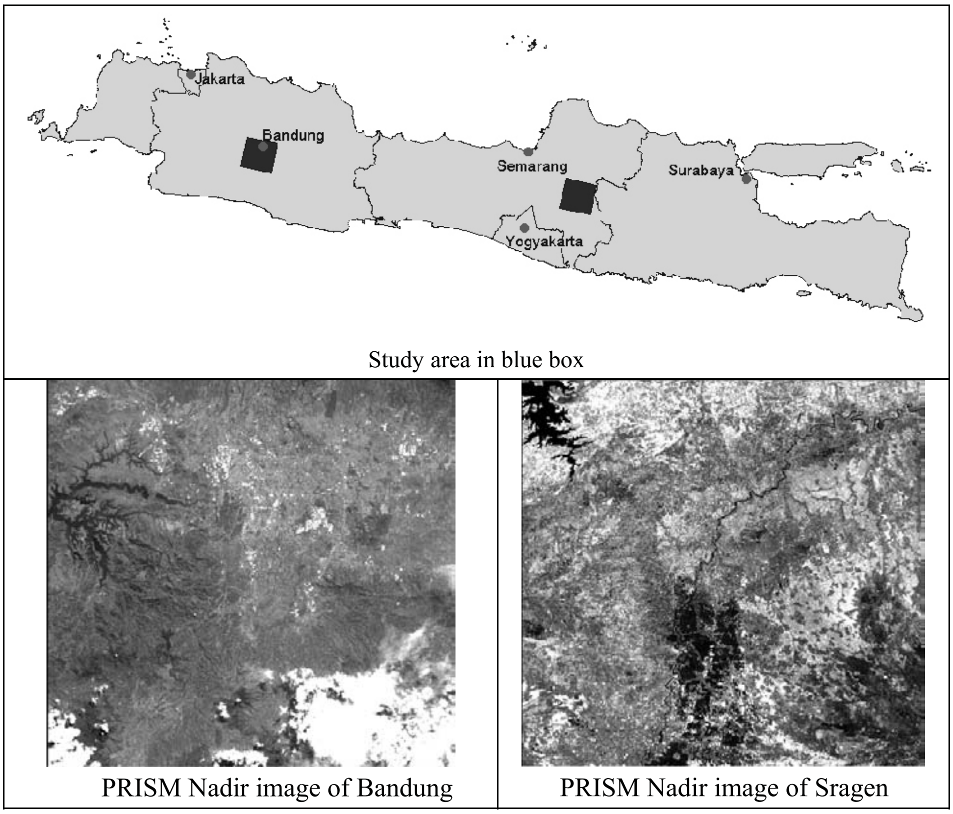
Year	Satellite sensor	Author	Accuracy (m)
2006	ALOS PRISM	JAXA	< 6.5 m
2008	ALOS PRISM	Bignone & Umakawa	2 – 5 m
2008	ALOS PRISM	Schneider et al.	4 m
2010	ALOS PRISM	Geo Image	5 m

The aim of this research was to study the possibility of IKONOS image and SRTM X-C band to be used as CP reference for ALOS PRISM DEM generation. The DEM of study area was generated using 2 kinds of GCPs/CPs: (1) using field measurement GCPs taken by differential GPS and (2) using CPs from

IKONOS image (XY coordinat) and SRTM for (Z elevation). The generated DEMs were compared. The accuracy of DEMs were examined by calculating RMSE (root mean Square Error) between the generated DEMs and another field measurement GCPs.

2. Method

The study area was Sragen area in Central Java province and Bandung area in West Java province which are shown by blue box in Figure 1. According to topography condition based on SRTM DEM, Sragens area has topography range from about 50 m to more than 500 m, and Bandung area has range from about 500 m to more than 2500 m in mountainous area. The DEM was generated using stereo pair ALOS PRISM (Nadir and Backward) level 1B2R with 2.5 m spatial resolution.



Study area in blue box

PRISM Nadir image of Bandung

PRISM Nadir image of Sragen

Figure 1. Location of study area

The method of this research was divided into 3 stages: 1) GCP/CP collection, 2) DEM generation, and 3) accuracy analysis of the generated DEM. In the first stage, the whole PRISM nadir image was divided into 20 area using grid line, and then each area was identified to determine location of GCPs/CPs which were located in sharp and clear object such as, corner of the crossroad, the edge of bridge, corner of the paddy field ect. Besides, GCPs/CPs must be well distributed in the whole image. Three dimensional of XYZ field measurement was conducted using differential GPS at each location. On the other hand, three dimensional of XYZ were also collected from IKONOS with 1 m spatial resolution (from Google Earth) for XY and SRTM X-C band (30 m spatial resolution) for Z in each location. Finally, it is obtained 21 GCPs and 21 CPs for Sragen area, but for Bandung area is only obtained 15 GCPs and 20 CPs for Bandung area. Distribution of 21 collected GCPs/CPs in Sragen Area is shown in Figure 2. These GCPs/CPs were used as input data for DEM generation process.

In the second stage, DEM was generated using the collected GCPs/CPs from the first stage. The flowchart of DEM generation process based on LPS modul of Imagine software is shown in Figure 3. 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. Next step was to build pyramid layer by making four levels of stereo images; master and target images as shown in Figure 4. 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.

The collected GCPs/CPs XYZ in the first stage were used as input data in the process. Based on 20-21 GCPs/CPs, transformation equation were built and then it was used to determine around 50-60 Tie Points (TPs) automatically. After that, the generated TPs were corrected and then converted to become CPs. Finally, the total number of CPs that used in the DEM generation process becomes 77 CPs. Previous research showed that the errors becomes stable and small, if we used CPs more than 60 (Trisakti et al., 2009).

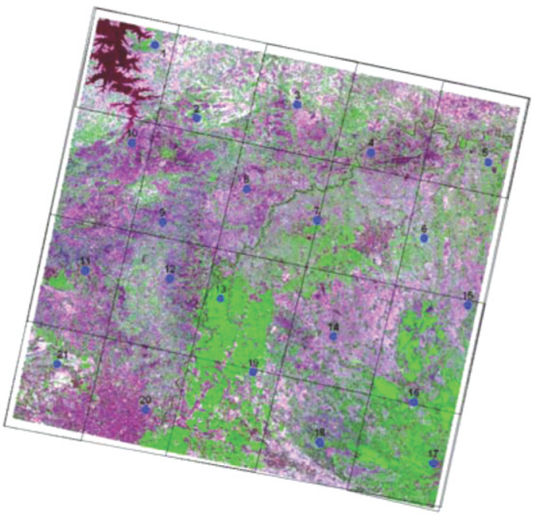
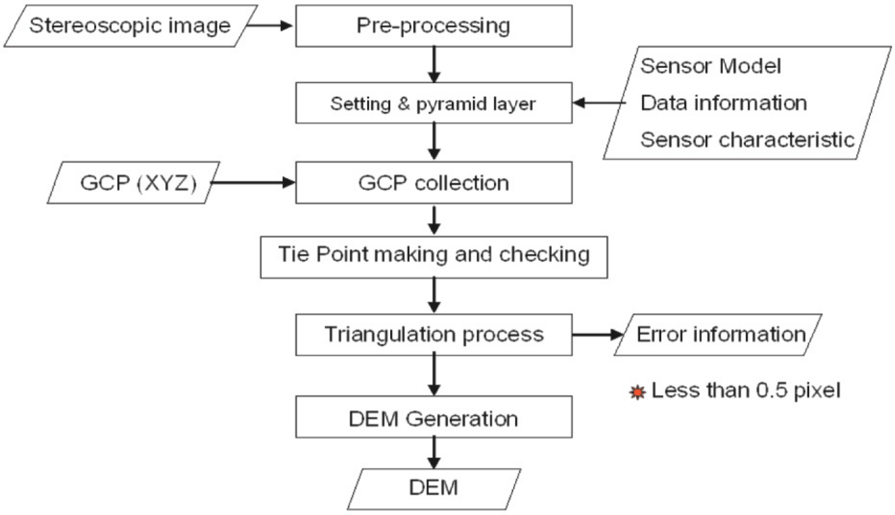


Figure 2. Distribution of 21 collected GCPs/CPs in Sragen area



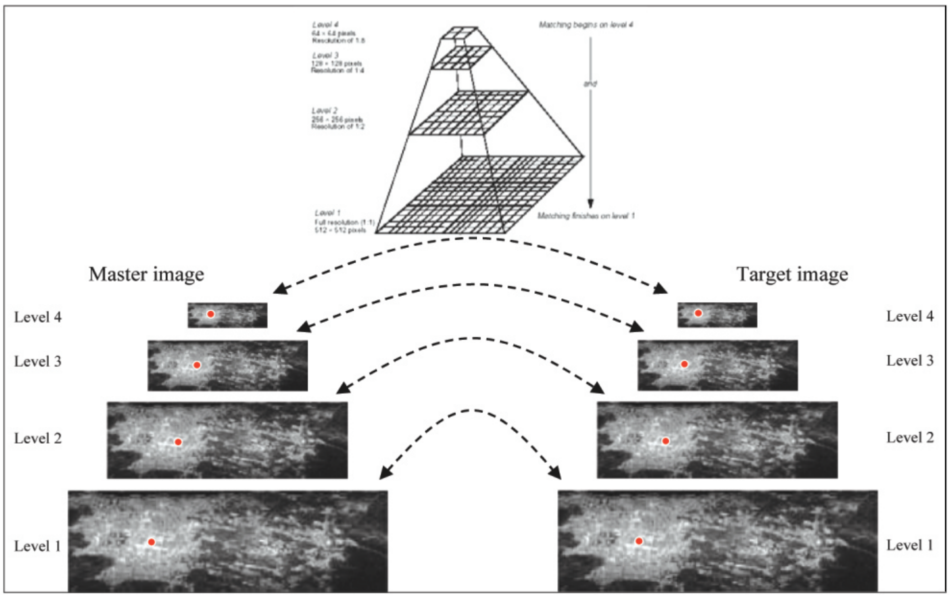


Figure 4. Pyramid layer of four levels of images (Leica Geosystems, 2002)

The triangulation process using collinear model was performed to establish relation among xy points on image (pixel coordinate) with XYZ coordinates on the earth surface (ground coordinate) 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.

The last step was image matching between master and target images to obtain relief displacement (parallax). This technique correlated area or pixel in master image with same area or pixel in target image based on grey value similarity of pixel. It was assumed that the same area or pixel on the stereo image had the higher coefficient correlation shown by Equation (1) than other areas or pixels (Leica Geosystems, 2002). Finally, the parallax was used to calculate elevation of each pixel using developed formulation from triangulation process shown in Figure 3.

$$\rho = \frac{\sum_{i,j}[g_1(c_1,r_1)-\bar{g}_1][g_2(c_2,r_2)-\bar{g}_2]}{\sqrt{\sum_{i,j}[g_1(c_1,r_1)-\bar{g}_1]^2\sum_{i,j}[g_2(c_2,r_2)-\bar{g}_2]^2}} \quad (1)$$

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,

ρ = 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

In the third stage, the accuracy of generated DEM was evaluated by calculating Root Mean Square Error (RMSE) (**Equation 2**) of height difference between the generated DEM with actual height measured using differential GPS. The calculation of RMSE was done at 7-14 points. This methods is also used in American National Map Accuracy Standard for evaluating the accuracy of DEM.

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2} \quad (2)$$

where,

N = Total number of sample
y_i = Height of generated DEM for sample i
x_i = Height of measured GPS for sample i

3. Result and Discussion

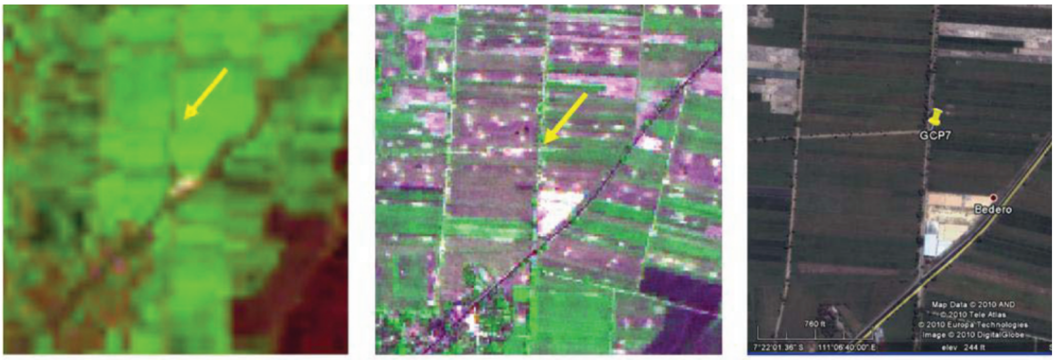
3.1. Consideration to use IKONOS Image (Google Earth) and SRTM X-C Band

This research used GCPs and CPs from the field measurement and from IKONOS image and SRTM X-C band respectivelly. GCP XYZ was measured using differrential GPS, and it has accuracy less than 1 m. It is considered as the best choice for DEM generation. On the other hand, IKONOS image and SRTM X-C band were used as horizontal (XY) and vertical (Y) reference due to some considerations.

The first consideration was that IKONOS image has higher spatial resolution ($\leq$1 m) comparing to PRISM ALOS (2.5 m), so it made easy to identify the same objek on the both images. In the previous research (Trisakti *et al*., 2009), Landsat Ortho from USGS was used as horizontal reference to collect CP for ALOS PRISM DEM generation, but it was hard to find the exact location on both images due to lower spatial resolution of Landsat image (15-30 m), which resulted the time consuming for CP collection stage and lower accuracy of the generated DEM. **Figure 5** shows a capability comparison of Landsat, ALOS PRISM and IKONOS images to identify the same object on the earth surface. Landsat image can not show the corner of the paddy field¸ but ALOS PRISM and IKONOS can exactly identified the location. So more accurate and good distribution of CP for whole ALOS PRISM image can be obtained by using IKONOS image as horisontal reference for CP collection.

The second consideration was related to the accuracy band. The horizontal and vertical accuracies of IKONOS and SRTM X-C were evaluated using 14 field measurement GCPs. It showed that the horizontal accuracy (RMSE) of the

IKONOS was 6.5 m and the vertical accuracy (RMSE) of the SRTM X-C band was 5.5 m. The horisontal accuracy of IKONOS was less than 3 pixel of ALOS PRISM, and the accuracy of SRTM X-C band was still in the range of ALOS DEM accuracy (Tabel 1). **Table 2 shows** the accuracy of SRTM data from the previous research. According to those accuracy, IKONOS image and SRTM X-C band was quite good to be used as reference to obtain CPs for ALOS DEM generation.



Landsat Ortho 30 m   ALOS 2.5 m   Citra Google Earth

Figure 5. Capability comparison of Landsat, ALOS PRISM and IKONOS Images (Google Earth) to identify the same object

Table 2. The accuracy results of SRTM DEM

Year	Satellite sensor	Author	Accuracy (m)
2005	SRTM X band	Gesch D.	3 – 5 m
2006	SRTM X-C band	Yastikh et al.	5 – 9 m

3.2. Comparison of The Generated DEM using GCPs and CPs

Figure 6 shows the generated DEM of Sragen area from ALOS PRISM stereo data using 21 field measurement GCPs (6a) and 21 CPs from IKONOS and SRTM X-C band (6b). Both DEMs has 10 m spatial resolution and are 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 topography range of the generated DEMs is same with the topography range of SRTM DEM as described in the previous part.

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 3. From those statistic values, both the generated DEMs have relatively same minimum, mean and maximum errors. The vertical accuracy of of the generated DEM using GCPs is 3.6 m and the horisontal accuray is 5.8 m. On other hand, the vertical accuracy of the generated DEM using CPs is 5.4 m and the horisontal accuray is 10.9 m. It means that comparing to the first DEM, the vertical accuracy of the second DEM decreases around 50 % and the horizontal accuracy decreases around 100%.

The difference height between the both DEMs was analysed using 2 methods. First method was DEM subtraction, and second method was height distribution along transect line. The result of DEM subtraction (DEM using GCPs – DEM using CPs) is shown in Figure 7, and the height difference of the both DEMs can be known by color gradation from pink-blue (-10 m) to red (10 m). According to the color gradation of Figure 7, the values of DEM using CPs was higher comparing to the values of DEM using GCPs. Almost of the DEM area had small difference (less than 1 m, range from -1 m to 1 m), it meant that both DEMs had relatively same height. The height difference with range from -6 m to -1 m could be identified in blue color, and it was also identified some spots with large height difference (more than 10 m). The large height difference happened in error pixels called "Bull eye". The "Bull eye" was usually occured in DEM generation process (miss in pixel matching process due to low contrast of stereo data, interpolation error due to less of mass points), and it was needed post processing to correct this kind of error.

The transect line and the result of height distribution along transect line are shown in Figure 8. The height distributions from the DEM using GCPs and CPs are shown in pink and red color respectivelly. Both of the height distributions are almost the same, even the height distribution of the DEM using CPs is higher in some parts comparing to the height distribution of the DEM using GCPs.

3.3. The Absolute Accuracy of The Generated DEMs

The absolute vertical accuracy of the generated DEM using measurement GCPs and CPs from IKONOS and SRTM X-C band were analysed using 14 GCPs from field measurement in Sragen area. The absolute difference between the DEMs and the GCP measurement at each point, and RMSE of all the points are shown in Tabel 4. DEM 1 was the DEM using GCPs from field measurement, and DEM 2 was the DEM using CPs from IKONOS and SRTM X-C band. The result showed that the DEM using CPs had lower vertical accuracy (5.6 m) comparing to the DEM using GCPs (3.5 m). It was around 60% lower accuracy.

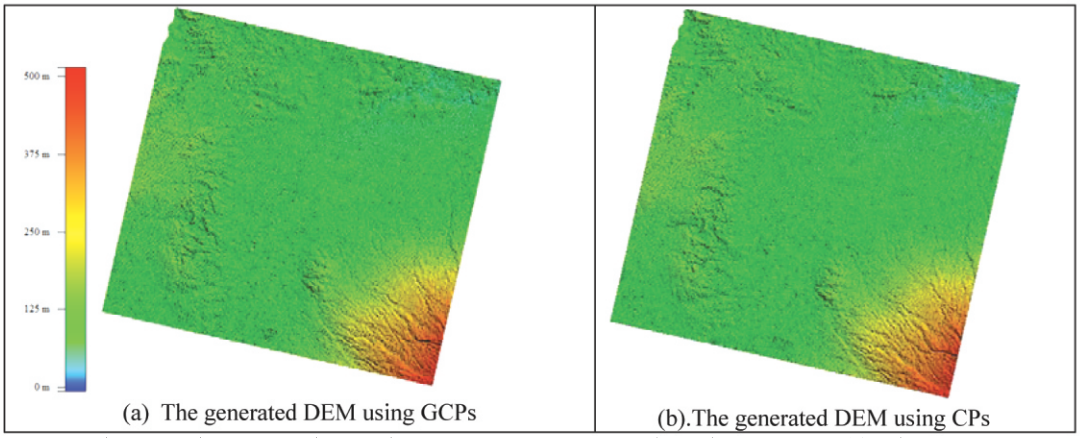


Figure 6. The generated DEM from ALOS PRISM stereo data of Sragen area, (a) using GCPs and (b) using CPs

Table 3. Accuracy report of the generated DEM (using GCPs and CPs) against total of 77 control points

	Using GCPs	Using CPs
Minimum, Maximum Error:	-9.9 m, 11.8 m	-18.4 m, 11.3 m
Mean Error:	-0.4 m	-0.3 m
Mean Absolute Error:	2.7 m	3.8 m
Root Mean Square Error (RMSE):	3.6 m	5.4 m
Absolute Linear Error 90 (LE90):	5.8 m	10.9 m

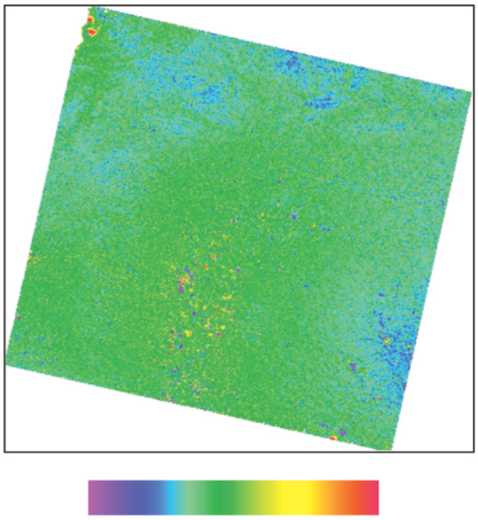


Figure 7. The result of DEM subtraction (DEM using GCPs – DEM using CPs)

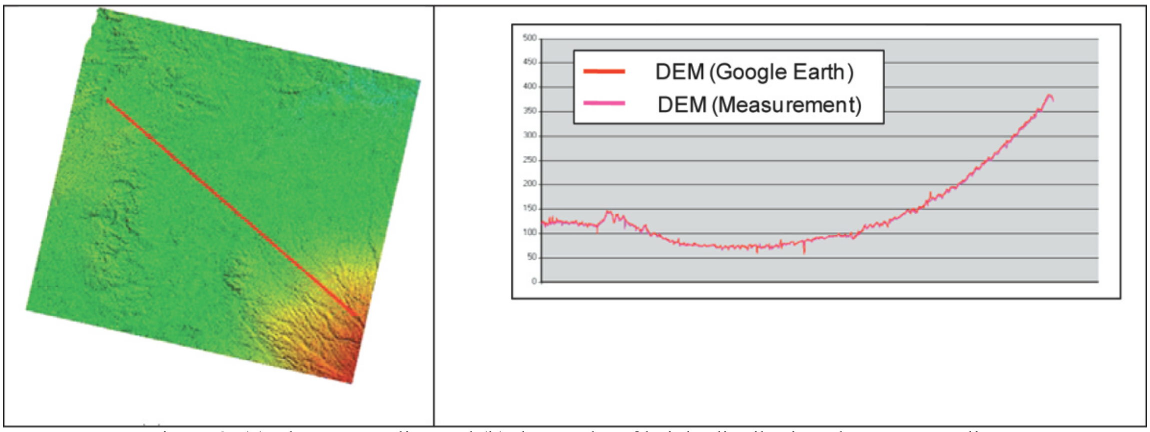


Figure 8. (a) The transect line and (b) the results of height distribution along transect line

Table 4. Comparison of absolute vertical accuracy of the generated DEM Using GCPs and CPs in Sragen area

GCP	Abs (Survei-DEM1) (m)	Abs (Survei-DEM2) (m)
1	2,5	3,4
2	5,7	6,0
3	1,8	3,0
4	1,2	0,7
5	1,6	5,5
6	8,3	18,5
7	2,7	1,7
8	0,3	4,5
9	7,5	2,8
10	11,0	4,9
11	2,8	2,6
12	0,2	18,8
13	1,3	4,9
14	8,3	4,6
RMSE	**3,5**	**5,6**

To know the consistency of the result, we also generated another DEM in Bandung area using the same method. The generated DEM of Bandung area using GCPs and CPs are shown in Figure 10. The both DEM is almost same pattern, and the height range is about 50 – 2000 m. The "Bull eye" is found in right part of the DEM using GCPs. It is considered due to the lack of GCPs input of this area (only use 15 GCPs). The absolute vertical accuracy of the generated DEM using GCPs and CPs were analysed using 7 GCPs from field measurement in Bandung area. The absolute difference between the DEMs and the GCP measurement at each point, and RMSE of all the points are shown in **Tabel 5**. The result shows that the DEM using CPs has lower vertical accuracy (7.1 m) comparing to the DEM using GCPs (4.0 m). It is around 80% lower accuracy. The result is not so different with the result of Sragen area.

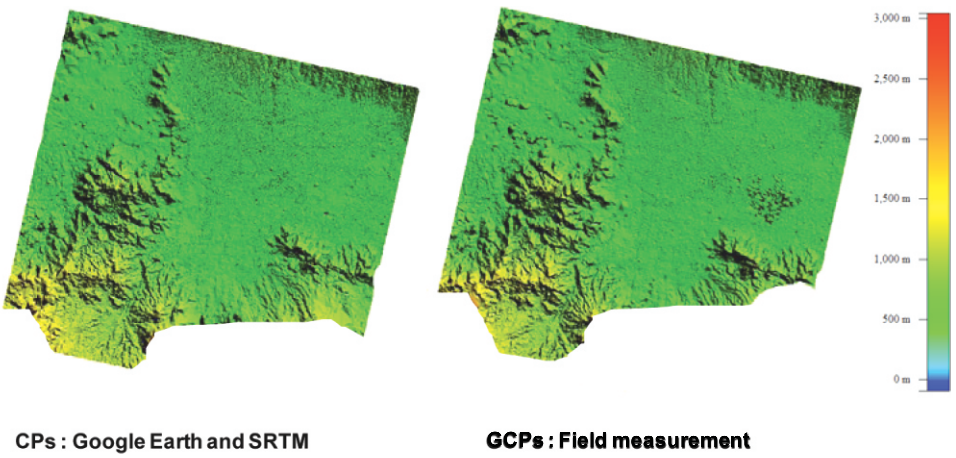


Figure 9. The DEM of Bandung area using CPs (left) and using GCPs (right)

Table 5. Comparison of absolute vertical accuracy of the generated DEM Using GCPs and CPs in Bandung area

GCP	Abs (Survei-DEM1) (m)	Abs (Survei-DEM2) (m)
1	11,9	1,7
2	5,5	2,9
3	2,0	17,7
4	5,2	16,8
5	8,6	3,0
6	2,0	4,0
7	1,0	13,0
RMSE	**4,0**	**7,1**

4. Conclusion

By using the IKONOS, accurate and good distribution of CP for whole ALOS PRISM image can be easily obtained. The horizontal accuracy of the IKONOS is 6.5 m (less than 3 pixel of ALOS PRISM) and the vertical accuracy of the SRTM X-C band is 5.5 m. These accuracy are quite good to be used as CP source for ALOS DEM generation.

- The accuracy of the DEMs against total of 77 control points used in DEM generation process shows that the vertical accuracy of the DEM using CPs decreases around 50% and the horizontal accuracy decreases around 100% comparing to the accuracy of DEM using GCPs.
- The DEM using CPs has almost same height pattern and height distribution comparing to the DEM using GCPs.
- The evaluation of Absolute accuracy of the DEM in Sragen and Bandung area shows that the DEM using CPs has 60% – 80% lower absolute accuracy comparing to the DEM using GCPs.
- IKONOS image and SRTM X-C band can be considered as good alternative of CP source to generate high accuracy DEM from ALOS PRISM stereo data

Acknowledgements

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