Quality Assessment of DEM Generated from SAR Radargrammetry Based on Cross-Correlation and Spatial Resolution Setting

R Arief1, A Setiyoko1,3, R Maulana1, S Ali1, D Sudiana2, A M Arymurthy3
1Remote Sensing Technology and Data Center, Indonesian National Institute of Aeronautics and Space (LAPAN), Jakarta, Indonesia
2Department of Electrical Engineering, Universitas Indonesia, Depok, West Java, Indonesia
3Faculty of Computer Science, Universitas Indonesia, Depok, West Java, Indonesia
rahmat.arief@lapan.go.id, andie.setiyoko@ui.ac.id

Abstract. DEM as a model of earth’s surface model plays an important role in the environmental analysis. The most common recent technology in producing DEM is SAR. Even though it has advantages compared to optical approach, DEM generated from SAR still has issues regarding process setting regarding cross-correlation and spatial resolution determination. Both aspects will affect the volume of output data and computational effort. This research project is aimed to analyze the effects of cross-correlation and spatial resolution determination in DEM generation process to its accuracy. Several experiment scenarios of cross-correlation and spatial resolution setting had been applied to TerraSAR-X data. Overall output is shown that determination of cross-correlation threshold and spatial resolution in processing stages will have a significant effect on the accuracy of DEM generated. Gaps of data often occur in several sets of both aspects.

1. Introduction
Digital Elevation Model (DEM) is a representation of our earth’s surface in the form of a digital number of elevation on a regular grid or raster. DEM requirement is enhancing due to the rapid development of spatial analysis for various purposes. The requirements will imply to techniques used to derive the data [1]. DEM derived from synthetic aperture radar (SAR) technology has been applied for urban area mapping [2]. DEM also had been applied to calculate the boreal forest aboveground biomass (AGB) and stem volume (VOL) imputation [3]. DEM generated from radargrammetry type of processing has been widely used to derive DEM for a remote area that highly possible to access [4][5], such as high latitude iced surface or arctic area [6].

DEM is possible to be generated from terrestrial measurement or remote sensing technologies. Terrestrial measurement requires a bigger effort compared to the remote sensing acquisition process. Recent DEM data mostly are taken by remote sensing platforms [7], for instance, satellite or airborne. Both optical and radar sensors could be used for DEM generation. Each of these data has advantages and disadvantages. This project is focused on radar acquisition because the technology can acquire the earth surface imagery day and night in all weather conditions [8][9][10][2]. Several techniques of
DEM generation from radar are interferometry and radargrammetry. Interferometry is developed that calculate the phase differences between the two images at the same location [11] [7]. While radargrammetry is based on stereoscopic photogrammetry approach [12], where there is a disparity between two images at the same location [7]. This project will focus on generating DEM from radargrammetry since it less affection from decorrelation caused by temporal and atmospheric condition [7]. The independency of this technology from atmospheric condition is an advantage upon interferometry technique [7]. Therefore to study and develop a novel technique to derive DEM from radargrammetry is still very challenging especially in an area where the atmospheric condition is dynamic.

There are several steps to process radargrammetry in order to solve the intersection of three-dimensional equations, which are viewing geometry, image matching, and geometric reconstruction [13]. The key success of the image matching step strongly depends on the geometric similarity if available stereo imagery [14]. It was already stated that in case of Radarsat radargrammetry reconstruction was easy, but the problem was on the stereo matching of SAR images that highly affected by speckle noise [11] [15]. In case of the images, the process of image matching usually based on two-dimensional normalized correlations and calculation of normalized cross-correlation coefficient on the gray scale of the image is common for this images [16]. Determining the right setting for cross-correlation is important in DEM generation from SAR images. The cross-correlation coefficient setting usually used for optical imagery produce noisy results with SAR data [15]. Several research projects have been developing several methods to overcome image matching problem in SAR data to generate DEM, such as cross-correlation experiments using the variation coefficient criterion [15]. Automatic matching techniques could be a robust solution and increase the accuracy of DEM [1]. It had been analyzed also that to have a correct image matching setting, the pyramidal algorithm could be applied [16]. The correlation surfaces combining method and the expanded correlation windows method has been developed to improve the image matching step [17] [13]. Then epipolar registration techniques had been conducted for stereo SAR radargrammetric data processing [14]. Latterly, an improved of multi-image matching techniques had been processed for stereo radargrammetry [18]. Experiments due to the correct number setting of cross-correlation had not been conducted previously. Beside cross-correlation setting, spatial resolution could impact to the accuracy of DEM produced [19]. Investigation and accuracy evaluation regarding different resolutions and image spacing were conducted previously by using Radarsat 2 imagery [19]. There was also experiment stated that low spatial resolution SAR images decreased the accuracy of the output DEM [7]. Regarding to the literature review of the previous research, the study of how cross-correlation and spatial resolution setting affect DEM generated from radargrammetry are still lacked.

Therefore this research is aimed to measure the accuracy of DEM generated from various scenarios of cross-correlation and spatial resolution determination in the processing. An experiment of quality assessment of DEM derived from various cross-correlation and spatial resolution setting is conducted and validated using a precise global positioning system (GPS) measurement data on the study area. The validation method would use root mean squared error (RMSE) and absolute error techniques that common for quality measurement for DEM [10].

2. Cross-Correlation and Spatial Resolution Setting

Cross-correlation and spatial resolution setting are required are very important due to the image matching process. Therefore two SAR images cross-correlation is processed. The higher cross-correlation threshold setting would cause a better image matching quality. In the case of SAR images, two-dimensional normalized correlation is the base of the matching process [16] [13] [6][18].

Spatial resolution or pixel spacing setting has a significant influence on reducing the error caused by speckle noise. Speckle noise would affect the image matching process. In this project, we used multilooking process to reduce speckle noise. If the multilooking area is getting wider in the direction
of range and azimuth then a lot of speckle noise would be reduced. This would make the image matching process more precise.

3. Accuracy Parameter
Quality assessments of DEM are quantified from several accuracy parameter calculations. There are an absolute error (1), RMSE (2), LE95 (3), and Missing Data (4). Absolute error, RMSE, LE 95 are accuracy analysis calculation commonly and standardized used for error detection for elevation [20].

\[
\text{Absolute Error} = \frac{\sum_{i=1}^{n} (Z_{ri} - Z_{mi})}{n} \quad (1)
\]

\[
\text{RMSE}_{z} = \sqrt{\frac{\sum_{i=1}^{n} (Z_{ri} - Z_{mi})^2}{n}} \quad (2)
\]

\[
LE_{95} \text{ Vertical Accuracy} = 1.96 \times \text{RMSE}_{z} \quad (3)
\]

Where \(Z_{ri}\) is the height of reference point \(i\) derived from higher accuracy measurement, \(Z_{mi}\) is a height of measured point \(i\) derived from the generated DEMs, \(n\) is the number of points being validated, \(i\) is an integer number from 1 to \(n\).

\[
\text{Missing Data} = \left(\frac{\text{Number of Nan Pixels}}{\text{Total Number of Pixels}}\right) \times 100 \quad (4)
\]

Missing data on generated DEM is calculated by defining Number of Nan Pixels, the number of pixels with no data defined divided by Total Number of Pixels in percentage.

4. Experiment
This experiment uses TerraSAR-X data that covered both plain and mountainous area. Location of data is in the western part of Java Island. The detail of the data is seen in Table 1.

| Specification       | Detail of both data                      |
|---------------------|------------------------------------------|
| Acquisition date    | 18\(^{th}\) June 2018 and 23\(^{rd}\) June 2018 |
| Satellite           | TDX and TSX                              |
| Product type        | SSC                                      |
| Polarization        | HH and HH                                |
| Orbit Direction     | Ascending                                |
| Incidence angle     | 21.24\(^\circ\) and 42.75\(^\circ\)      |

The TerraSAR-X dataset contains two images acquired with 5 days different in the study area, which is shown in Figure 1.
The study area is located on the box of Figure 1, which is located in an area where there are two topographic characteristics occur, plain and mountainous. The area also has multi landcover objects, such as paddy field, settlement, etc. The processing procedure was conducted using Scarscape. The steps were initialized by defining the master image and the slave image. Then it was followed by coregistration stage which was assisted by another DEM data. In this case, the Shuttle Radar Topography Mission (SRTM) data was used. At this stage, the cross-correlation threshold and spatial resolution were set on a specific number. Cross-correlation threshold numbers applied were: 0.25; 0.45; 0.65. While spatial resolution setting numbers applied were: 6 m; 12 m; and 24 m. The spatial resolution setting is based on the spatial resolution of WorldDEM4Ortho product which is 0.8 arc seconds (approx. 24 m) in latitude direction [21] and the spatial resolution of WorldDEMCCore, 12 m [22].

Ground control points were deployed in shift refinement and flattening stage. Elevation data was generated after the shift to height conversion. Generally, all process is shown in Figure 2.

5. Result and Analysis
The outputs of this experiment were nine DEMs varied of cross-correlation threshold and spatial resolution setting as shown in Table 2. The figures as shown in Table 3, the bigger cross-correlation threshold value the more gaps of data existed. DEM with cross-correlation threshold value 0.25 and the spatial resolution setting is 24 meter has full of height data value compared to DEM with cross-correlation threshold value 0.65 and the spatial resolution setting is 6 meter. The last mentioned type of DEM has too many gaps of data. Therefore cross-correlation and spatial resolution setting during the process of Terra SAR X would affect the quality of DEM generated.

In order to measure the accuracy of the output, all DEMs would be validated using precise height data acquired using GPS differential measurement. Accuracy analysis methods are the root mean squared error (RMSE), absolute error, and LE 95. LE95 value is the difference between the validation point and the DEM with an optional geoid offset, known as the linear error at the 95% confidence level [20]. The horizontal datum used in this research is World Geodetic System, WGS 84 and the vertical datum is EGM 96 (Earth Gravitational Model 1996). The accuracy of each DEM is shown in Table 3.
Figure 2. Research experiment flowchart

Table 2. DEMs as the outputs of the research experiment

| Cross-Correlation Threshold/Spatial Resolution | 6 meter | 12 meter | 24 meter |
|-----------------------------------------------|---------|----------|----------|
| 0.25                                          |         |          |          |
Table 3. Accuracy analysis of DEMs generated (meter)

| Height Variations | Cross Correlation Threshold | Spatial Resolution (m) | 0.25 | 0.45 | 0.65 | SRTM | AW30D |
|-------------------|-----------------------------|------------------------|------|------|------|------|------|
|                   | Abs. E                      | 6.77  8.69  11.75  2.98 | 5.78 | 9.80 | 3.87 | 3.57 | 7.51 | 3.91 | 1.92 |
|                   | RMSE                        | 8.45  12.05  14.27  3.73 | 8.33 | 12.13 | 4.77 | 4.46 | 9.45 | 4.68 | 3.06 |
|                   | LE 95                       | 16.56  23.62  27.97  7.31 | 16.33 | 23.77 | 9.35 | 8.74 | 18.52 | 9.17 | 6.00 |
| H<700 m           | Abs. E                      | 6.64  9.38  12.19  3.34 | 5.70 | 9.93 | 5.47 | 3.67 | 7.99 | 1.58 | 1.09 |
|                   | RMSE                        | 7.25  13.11  15.55  4.36 | 7.62 | 13.91 | 6.48 | 4.44 | 10.99 | 1.81 | 1.28 |
|                   | LE 95                       | 14.21  25.70  30.48  8.55 | 14.94 | 27.26 | 12.70 | 8.70 | 21.54 | 3.55 | 2.51 |
| 700<H<800 m       | Abs. E                      | 6.58  8.13  12.81  3.05 | 1.92 | 9.85 | 3.8  | 2.41 | 6.78 | 4.90 | 2.61 |
|                   | RMSE                        | 8.19  10.59  14.72  3.53 | 2.91 | 10.48 | 5.35 | 3.20 | 7.60 | 6.68 | 3.68 |
|                   | LE 95                       | 16.05  20.76  28.85  6.92 | 5.70 | 20.54 | 10.49 | 6.27 | 14.90 | 13.09 | 7.21 |
| H>800 m           | Abs. E                      | 7.86  8.79  6.40  3.81 | 8.93 | 9.12 | 4.08 | 5.04 | 6.94 | 3.87 | 2.60 |
|                   | RMSE                        | 9.33  11.99  6.91  4.15 | 11.03 | 10.34 | 4.38 | 5.78 | 8.05 | 4.89 | 4.13 |
|                   | LE 95                       | 18.29  23.50  13.54  8.13 | 21.62 | 20.27 | 8.58 | 11.33 | 15.78 | 9.58 | 8.09 |

Height variations classified into 3 categories due to the location area height range 656-1816 m. The characteristics of the study area where the elevation below 700 m is mostly plain and at others elevation levels are the hilly or mountainous area.
Based on Figure 3, overall accuracy increases as the cross-correlation setting is bigger. The most accurate DEM is derived from cross-correlation setting 0.45 and the spatial resolution setting is 6 m, which has overall absolute error 2.98 m. The least accurate DEM is derived from cross-correlation setting 0.25 and the resolution spatial setting 24 m, which has overall absolute error 11.75 m. While overall the more spatial resolution the more absolute error occurred.

According to DEM profile analysis, as shown in Figure 4, at the cross-correlation threshold (CCT) 0.25, there are some errors of height value determination. The errors are indicated by extremes height values especially for 24 m resolution setting (red) compared to SRTM (blue). The phenomenon is highly seen in the plain area. Meanwhile, at the higher setting of CCT, the DEM result is smoother, relatively fitter with SRTM surface, however, the problem of missing values occurs in some areas. So there is a tradeoff between the error of height and missing values at the setting process of the cross-correlation threshold. All in all the higher CCT is defined the lesser error obtained but the risk of missing values occurs.
The correct setting of CCT could be derived from the graph seen in Figure 5, where if we decide to produce DEM with RMSE accuracy on a specific value, 4 m RMSE accuracy for an instance CCT will be set on about 0.45 for 6 m resolution of TerraSAR-X DEM generated from radargrammetry. Similarly process, CCT is about 0.55 to generate DEM with 12 m resolution and RMSE accuracy 6 m.

According to the percentage of missing values, as seen in Table 4, the most missing data of elevation is the DEM with CCT 0.65 and 6 m spatial resolution setting. The least missing data is found on the DEM with CCT 0.25 and 24 m spatial resolution setting. The analysis results shown that we have to aware to the risk of missing value if the spatial resolution and CCT setting are higher for spatial analysis application.

### Table 4. Missing data of DEMs

| Spatial Resolution (m) | CCT 0.25 | CCT 0.45 | CCT 0.65 |
|------------------------|----------|----------|----------|
| 6                      | 1.28468% | 6.82507% | 34.78235%|
| 12                     | 0.31651% | 2.36805% | 11.38946%|
| 24                     | 0.00003% | 0.75682% | 3.93833% |

### 6. Conclusion

Determination of cross-correlation threshold and spatial resolution in processing stages will have a significant effect on the accuracy of DEM generated. The radargrammetry error is affected by the cross-correlation threshold and spatial resolution setting. Based on this experiment, by increasing the cross-correlation threshold we could increase the DEM accuracy, however, the trade-off is the missing values. These findings might lead that defining CCT and spatial resolution could contribute to the quality of DEM as the output of the process.

This research still has many options for development. According to the gap that occurs on particular DEM produced in the specific setting of cross-correlation and spatial resolution setting, interpolation or fusion techniques might be applied to fill the gap. Several projects for the problem has been conducted previously. Further research will continue to develop the interpolation experiment for DEM gap filling as well as fusion experiment with other data.

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