A fusion of digital elevation model based on interferometry SAR technique from ascending and descending path in urban area

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Abstract. The height of the earth's surface can be measured using synthetic aperture radar (SAR) images using interferometry (InSAR). The InSAR method uses phase information to produce the height of the earth's surface. The accuracy of the DEM produced by InSAR depends on the shadow, the layover area, and the coherence of two SAR data. This paper proposes a technique for combining DEM derived from the InSAR method from ascending and descending paths using high resolution TerraSAR-X / TanDEM-X. Generating DEM was done by the InSAR method which covers the same test area and came from one pair of ascending TanDEM-X images and one descending pair of TerraSAR-X. The combination of the two DEMs from the ascending and descending path has been done by assessing the weighting factors so that the accuracy of the DEM can be increased. The weighting factors are calculated from the height error map, layover and shadow map. The height error map is calculated from the interferometric coherence with geometrical considerations and the layover and shadow map is calculated using TerraSAR-X/TanDEM-X DEM. The images pairs with 33 angles and 37 degrees were used in this study for the InSAR method in urban areas (Jakarta city). The experimental results show a significant reduction in missing pixel counts due to layover, shadow and low coherences after combining.

1. Introduction

Jakarta, the capital city of Indonesia is always overshadowed by the threat of flooding that can strike at any time. Widespread flooding in this large city occurred in 1996, 2002, 2007 and 2013 inundating up to 40% of the city [1]. One of several applications that have direct relevance to the information needs of urban planners and engineers is creating a Digital Elevation Model (DEM) from contour and spot height information to be used for studies of surface water drainage etc. The DEM created from the Synthetic Aperture Radar (SAR) images is the best work in the history of remote sensing to date. The use of DEM is often found in many remote sensing applications [2], such as making of relief maps, terrain parameters extracting for geomorphology, water flow modelling for hydrology, modelling of earth surface movements, rendering from 3-dimensional visualization, analysing line of sight, monitoring accurate agriculture and forestry and infrastructure engineering design.

DEM quality is shown on vertical and horizontal accuracy on each pixel (absolute accuracy) and accuracy according to surface morphology (relative accuracy). Several factors that influence the quality of DEM products are: density of samples when obtaining elevation data, pixel size, correlation of data sources, surface terrain conditions, elevation data formation, vertical resolution, and quality of masking data such as coastlines, lakes, rivers, clouds and snow, algorithms with interferometry, radargrammetry, morphometry and interpolation algorithm (linear, relax, kriging) [3].

One DEM generation technique is to use the Interferometric SAR technique by extracting information on the terrain topography from the SAR signal phase. The InSAR technique is based on the processing
of complex SAR images obtained from slightly different incidence angles. This technique was applied for the first time by researchers at JPL (Jet Propulsion Laboratories) in 1986 using SAR data from airborne aircraft [4]. Today, a large number of research groups are working on the generation of DEM with InSAR data acquired from various airborne and spacecraft. The advantages of DEM generation from InSAR are related to high spatial resolution, good precision potential and highly automated DEM manufacturing capabilities. DEM is derived from phase information using the interferometry processing methods of 2 radar satellite images obtained from the same two orbit paths so that the difference in satellite geometry is very small (or a small baseline of about 50-200 m) and the time difference is as small as possible. Ideally the acquisition is carried out simultaneously to reduce surface changes as small as possible, such as the acquisition of DEM from SRTM satellites which are equipped with 2 receiving antennas along 60 m or tandem 2 satellites from TerraSAR-X and TanDEM-X.

There are still some inconsistencies in InSAR-based DEM due to inherent geometric distortion, namely, layover and shadow effects, in complex topographic areas and coherence of image pairs that are low during the phase-unwrapping process [5]. Layover and shadow are two geometric aberrations that are very common in SAR images on complex terrain areas. This is because the SAR image was acquired by looking sideways geometrically. Layover occurs when the terrain is steeper than the incidence angle. The shadow image in the SAR image shows a return of zero signals from an area not illuminated by radar and occurs when the rear tilt field is greater than 90 degree subtracted by incidence angle. This layover and shadow effect on SAR images causes a severe impact on the quality of the reconstructed elevation value [6].

Each DEM product from both ascending and descending path has varying levels of accuracy and characteristics and has advantages and disadvantages. This diversity of characteristics in obtaining DEM encourages interesting techniques, namely fusion of two methods to complement each other's shortcomings.

Several fusion methods have been carried out in the DEM production, such as: a combination of optical DEM and SAR [7], construction of a combined StereoSAR and InSAR model built in the same system coordinates [8] and adjusting Range Doppler and phase equations. Combining two methods to suppress artefacts that appear in the InSAR process from ERS1 and Radarsat1 data [9].

This paper proposes the method of combining InSAR and StereoSAR in producing DEM using high resolution SAR images by determining weighting factor for layover and shadow map slope, coherence, to complement each weakness in both methods and obtain better height accuracy.

2. Methodology

2.1. Data

The data in this study used TerraSAR-X / TanDEM-X satellite imagery that carries a high-frequency X-band SAR sensor and can be operated in flexible imaging mode. Data is produced in the Single-look Slant-range Complex (SSC) format in StripMap mode with HH polarization. The study area is around Jakarta city of Indonesia. It covers almost Jakarta, Tangerang, Bekasi and Depok with maximum elevation of 150 m from the mean sea level. It is one of the most populous urban regions in Indonesia and consists of dense urban settlements, bare land, and hilly areas. The city has also several bays, lakes, and creeks. Figure 1 shows data used for the research. The TerraSAR-X image pairs used for interferometry DEM have almost the same coverage for both ascending and descending paths and have small difference of incidence angle. In Table 1, there are 2 pairs of data for the interferometry method, with an angle of incidence around 33° and 37°. The greater the incidence angle, in a high area (such as mountains or tall buildings) will cause bigger geometric distortion so that the image pair for interferometry was chosen with the smaller incidence angles. The pair was acquired in a repeat pass
orbit which has an acquisition time difference of 11 days. With the above conditions, a short distance and time baseline is obtained. This condition is suitable for making inSAR DEM.

![Figure 1 Coverage of TERRASAR-X and TANDEM-X data for DEM generation](image_url)

**Figure 1** Coverage of TERRASAR-X and TANDEM-X data for DEM generation

| No | Product Name | Mission | Incidence Angle | Acquisition Date | Product Type | Polarization | Pass |
|----|--------------|---------|-----------------|------------------|--------------|-------------|------|
| 1  | TDX1_SAR     | Stripmap| 37,26           | 16 March 2018    | SSC          | HH          | Ascending |
| 2  | TDX1_SAR     | Stripmap| 37,24           | 27 March 2018    | SSC          | HH          | Ascending |
| 3  | TSX1_SAR     | Stripmap| 33,13           | 12 March 2018    | SSC          | HH          | Descending |
| 4  | TSX1_SAR     | Stripmap| 33,13           | 23 March 2018    | SSC          | HH          | Descending |

The fusion process is carried out using data from the DEM creation based on Interferometry SAR method from both ascending and descending path.

### 2.2. Research Method

The steps used to process DEM fusion in general can be seen in Figure 3. The picture presents the research framework starting from the use of research data, the order of making each DEM, weighting factors, and the fusion process until the comparative analysis of DEM results.
Figure 2. Flowchart of proposed fusion method

The interferometry method to obtain DEM is done through the stages: co-registration of both data with sub-pixel accuracy, spectral filtering, and generating interferogram. After getting the interferogram, a phase ramp reduction process and phase unwrapping are carried out, then the next step is converting the phase to terrain height, and the last step ends with geocoding.

2.2.1. Fusion method

A new elevation value in a same point is obtained from the merging of the Ascending InSAR and Descending InSAR data. The availability of several measurements of elevation at the same point will increase the accuracy for DEM fusion rather than the individual DEM [10].

The fusion method is carried out by weighting the DEM images resulting from Ascending InSAR and Descending InSAR as described in previous section. The weighting values for each pixel of Ascending InSAR and Descending InSAR processed results were calculated.

In simple terms, the steps in the fusion method are as follows:

- Set background value, if there is no DEM
- Set weighting value
- Set the height value, if the pixel is only 1 DEM
- Set weighted average values

\[ h_{out} = \frac{\omega_1 h_1 + \omega_2 h_2}{\omega_1 + \omega_2} \]  \hspace{1cm} (1)

where:
- \( h_1 \) elevation value from DEM 1
- \( h_2 \) elevation value from DEM 2
- \( \omega_1 \) weighting value from elevation DEM1
- \( \omega_2 \) weighting value from elevation DEM2

2.2.2. Weighting factor definition

In the DEM fusion method, we used the weighting value of the high error map for each DEM to provide the better accurate results. Making high error maps as a prerequisite is very important to be able to determine high or low weighting values. High error maps can be produced by considering various sources of error. Image geometry distortion such as foreshortening, layover [11, 12] and
shadow [13] given a low weighting value. The high coherence in both images shows no change in objects, so the accuracy of the elevation value is higher. But, low coherence indicates low accuracy.

The weighting factor of error maps is shown in Table 2.

| Coherence   | Weighting value |
|-------------|-----------------|
| 1 – 0.8     | 1               |
| 0.8 – 0.6   | 0.8             |
| 0.6 – 0.4   | 0.6             |
| 0.4 – 0.2   | 0.4             |
| 0.2 – 0      | 0.2             |

2.2.3. Accuracy validation

The results form DEM generated from ascending, descending path and fusion of both paths were tested for their height values with the results of more precise LIDAR data located in the study area. DEM data is processed from LiDAR data to get contour data and ground surface height. Figure 3 shows the DSM contour data in Pesanggrahan District as well as the ground surface height of the local area used for reference data. The LIDAR data distribution compare with the ascending and descending data footprint can be seen in Figure 3.

![Figure 3. Pesanggrahan River: (a) LiDAR data, (b) color-coded Elevation data from LiDAR, and (c) detailed area](image)

The comparison of DEM results that have been made both the InSAR, StereoSAR and proposed fusion method were analyzed through an accuracy assessment process using absolute errors (RMSE), Root Mean Square Error (RMSE) and Linear Error (LE95) [14].

\[
| Error Z | = \frac{\sum|Z_0 - Z_i|}{n} \tag{2}
\]

\[
RMSE_z = \sqrt{\frac{\sum(Error Z)^2}{n}} \tag{3}
\]

\[
LE95 = 1.96 \times RMSE_z \tag{4}
\]

where :
- \( Z_0 \) Elevation value from LIDAR
- Zi Elevation value from ascending, descending InSAR, or proposed method
- n Number of Measurement points

3. Result and Discussion
DEM extraction was carried out using multilook to reduce speckle in the DEM elevation with a spatial resolution of 12 meters was obtained. The data coverage used in this study is 30x50 km in the area around Jakarta.

![Elevation value of (a) ascending InSAR, (b) descending InSAR and (c) fusion method](image)

Figure 4 shows the profile plot of elevation of the three DEMs and LIDAR. The plot is taken in the area with elevation values in all three DEM results and LIDAR data, so the plot can be compared. The blue colour shows the DEM plot using the Ascending InSAR method, yellow using Descending InSAR, green is the result of the fusion method, and red is the LIDAR data. The x axis indicates the distance from first point taken and the y axis is the elevation value.

![Comparison of profile plot of DEM ascending, descending, fusion and LIDAR data](image)

Figure 5. Comparison of profile plot of DEM ascending, descending, fusion and LIDAR data

From equation (1) it appears that the results of the DEM fusion will show values between the elevation values of DEM InSAR and StereoSAR, which are then proven in Figure 5. The trend of DEM plots Fusion to Ascending InSAR or Descending InSAR DEM depends on the weighting of w1 and w2.
The height accuracy test shows that the fusion method have absolute error values of 3.72 meters with the Root Mean Square Error (RMSE) value of 4.73 meters. As stated in Table 3, the absolute error values using the Ascending and Descending InSAR methods are 7.13 meters and 3.39 meters and RMSE 8.74 meters and 4.27 meters. Finally, the LE95 value from Ascending InSAR, Descending InSAR, and fusion method are 17.13, 8.38, and 9.28 meters.

**Table 3** Height accuracy of ascending, descending InSAR and proposed fusion methods compared to LIDAR data.

|                | Absolut error [m] | RMSE [m] | LE95 [m] |
|----------------|-------------------|----------|----------|
| Ascending DEM  | 7.13              | 8.74     | 17.13    |
| Descending DEM | 3.39              | 4.27     | 8.38     |
| Fusi DEM       | 3.72              | 4.73     | 9.28     |

4. Conclusion

Generation of DEM values by a combination of InSAR descending and ascending methods using TerraSAR-X / TanDEM-X data based on weighting the high error map has been successfully carried out. The results of the fusion of descending and ascending created DEM have a spatial resolution of 12m and show lower accuracy from proposed method compared to InSAR method using descending path.

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