Quality assessment and validation of TerraSAR-X digital surface model using LiDAR for urban areas in Jakarta

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Abstract. Digital Surface Models (DSMs) are highly important product obtained from either conversional measurements or from remote sensing imagery. The estimation of height modelling of the earth's surface is measured using interferometry synthetic aperture radar (InSAR). This radar technique uses phase information to provide the peak of the surface. The accuracy of the DSMs produced by InSAR depends on shadow mask of the area, layover, and the coherent difference between the images. This paper proposes a quality of DSMs derived from the InSAR method, which is from ascending paths using high resolution TerraSAR-X. In this research we generate DSMs in Urban area in Jakarta. Generating DSMs was done by the InSAR method which covers the same test area and came from one pair of ascending TerraSAR-X images. The quality level of elevation to be validated compared to validation datasets and application requirements. The comparison of the two DSMs from the ascending has been done by validating with LiDAR. The images pairs with 37 degrees incidence angle for ascending path. The results show error distribution within different terrain characteristics, which are presented using various ways including statistics, error maps and profiles. There is significant reduction in missing pixel counts due to layover, shadow and low coherences after co-registered. These include terrain characteristics, vegetation and land cover. For different slope we found accuracy to decrease with slope increase with an average standard deviation between a very low slope class and very steep slope class. The study area where we analyse is Jakarta for urban area.

1. Introduction

Numerous cities within the world are battling with a horde of urban issues [20]. In the case of Jakarta, broad flooding in this huge city happened in 1996, 2002, 2007 and 2013 inundating up to 40% of the city [1]. As we know Jakarta is capital city of Indonesia, so an increase in population every year. Given the increasingly widespread impact of floods in Jakarta, methods are needed to assess current flood risk and estimates for the longer term [2]. One of several applications that have direct relevance to the information needs of urban planners and engineers are creating a surface elevation model. The model of height made from different phase between pair radar images.

This innovation uses radar as an implication to observe ground which means not being affected by clouds and time in distinguishing from detection optically inaccessible which is influenced by clouds and since it can work during the day when there’s such a daytime. The images which used in this study are TerraSAR-X. TerraSAR-X was launched in 2007 into space, high frequencies travel with x band sensors, varies supported on the imaging mode followed by TanDEM-X in 2010. TerraSAR-X resolution ranging around 1 m for its SpotLight mode to 40 m for Wide-ScanSAR mode. In generally
the mode of TerraSAR-X imagery is in its StripMap mode incorporates a resolution of three meters [4]. Digital Surface Model (DSM) is a digital that represents all features on the surface of the earth such as trees and houses while Digital Terrain model (DTM) represents the surface of the earth without all these features [11].

There are several techniques of DEM extraction from radar including interferometry and radargrammetry. An interferometry technique was developed that calculates the phase difference between two images at the identical location and also the angle of incidence [9] [14] [17]. For the radargrammetry technique was supported stereoscopic photogrammetry approach, where there are differences between two images at the identical location. In this case, the study to create the height estimation of the surface of the earth will focus on DEM extraction using interferometry technique since it's less affection from decorrelation caused by temporal baseline and the shape of the atmosphere. In studying and developing techniques for DEM extraction from interferometry is still very challenging and must determine several parameters that must be done alone especially in areas that are sensitive to change such as urban areas and so on. The high estimation modelling comes from phase differences which are called topographic phases. The baseline perpendicular of the radar satellite should be around 50-200 m between the images.

The surface elevation model will have significant difference with terrain model where the DSM reflects the visible surface, including vegetation and buildings. While DTM is the height of land surface to mean sea level. Another factor to consider is the coherence. Coherence is the similarity of recording images in the same location with different times. The minimum recommended coherent factor is 0.5 to get results with high accuracy [5][14]. For this case, the elevation estimation gaps occur because of layover and shadow, especially in extreme areas like on high mountain plains. At the last, we need to compare the results with LiDAR data as validation and show an assessment of the quality the Digital Surface Model from TerraSAR-X in Jakarta for urban areas.

2. Methodology

2.1. DSM Extraction

In this study the final DSM generation using TerraSAR-X images be composed from two results such as DSM extraction and validation. In the surface model extraction, the processing steps will show in figure 1. It displays the information processing steps for both stages of DSM generation methodology.

There are several complex steps for the processing of the estimated height of extraction by interferometric radar and depend characteristics of image. The beginning processing of interferometry, a minimum of two concurrent images of the chosen field, provides prerequisites for interferometry. To achieve high accuracy results, the beam and mode of the satellite images must be the identical geometry for the foremost coherent images and therefore the scene period must be same as avoid atmospheric decorrelation because of varying seasons [19]. For the co-registration and baseline perpendicular estimation processing, the imagery that has more past time can be used as master and the other image which is a pair image is used for slave image. Between pair of the images should be overlapping area and no gap to get sub-pixel with high accuracy and the results will be good. The co-registration parameter for radar satellite imagery is carried out for two parts, first step for coarse coregistration and last step fine coregistration for the value of the parameter we can modified by our self depends on the type of the images like spotlight, stripmap and so on [13].

Initially, the situation of every pixel within the slave scene changes with relevancy the master scene. For this case, the phase and amplitude for slave scene information is recalculated for every pixel can be interpolated using cubic convolution functions or bilinear interpolation [8]. The resampling of slave imaging method was chosen supported the kind of terrain and therefore the complex SAR image quality. There are some parameters for coregistration such as the position azimuth grid, dependencies, numbers of window, range grid position, orbit, accuracy, interpolation and initialization. That all the parameters value should be modified by our self or can set default to calibrated. In addition, the centre positions of azimuth and range, cross-correlation threshold and sizes of window must be established. At the final,
the smooth shift parameters must be determined, as well as the size of window containing, the azimuth and range window numbers, value of cross-correlation oversampling, oversampling of the coherence, the threshold of signal to noise ratio (SNR).

**Figure 1. Flowchart of Final DSM**

In Figure 1, shows the process how to get final DSM with accuracy assessment information in Jakarta for urban areas. In part one show us how to get the DSM using TerraSAR-X and last part in the validation of the DSM using LiDAR. And the study area which we analyzed will show in figure 2.
In co-registration processing the amount of grid density, the size of the window and coefficient of the cross-correlation threshold are very important because it will affect the number of pixels that will displayed on the results and accuracy of height estimation model. These parameter values are normally determined by repeated tests [19]. The estimation of InSAR stack is the overview for stack images are used for processing. It gives us completely information about pair of images, such as; baseline estimation, height of ambiguity, baseline perpendicular between two images and the others. We will show about characteristics data we used in this study in table 1.

Table 1. The characteristics of TerraSAR X imagery

| Characteristics            | Master               | Slave                |
|----------------------------|----------------------|----------------------|
| Product                    | TDX1_SAR             | TDX1_SAR             |
| Acquisition mode           | Strip map            | Strip map            |
| Acquisition date           | 2018-03-16           | 2018-03-27           |
| Product type               | Single look Slant range (SSC) | Single look Slant range Complex (SSC) |
| Polarization               | HH                   | HH                   |
| Pass Direction             | Ascending            | Ascending            |
| Incidence angle            | 37.26                | 37.24                |
| Length and width of image  | 30 km x 50 km        | 30 km x 50 km        |

The table 1 showed that description of pair TerraSAR-X which used in this study. We can see the time difference is 11 days. TerraSAR-X with StripMap mode has high resolution with spatial 3 m. The stack of between two images information will show in table 2.

Table 2. InSAR Stack Estimation

| Overview                      | Values   |
|-------------------------------|----------|
| Perpendicular baseline        | 77.11 m  |
| Temporal baseline             | 11 days  |
| Modelled coherence            | 0.92     |
| $2\pi$ height of ambiguity    | 77.05 m  |
From table 2, we can estimate the result and set the parameter. During the processing we set some parameter based on our precious research [11] [14] [17]. Based on multi looking in interferogram generation, cross correlation, coherence threshold and phase unwrapping method. The modelled coherence should not below 0.8 due to more of pixels based between master and slave are not matched. There are basically different concepts of interferometry; single pass along track, single pass across track and repeat-pass interferometry. In this case, two scene of radar data sets are accomplished concurrently or disparate times using different point of view for the identical area of interest in this field for the repeat pass interferometry. This data set contains magnitude of the radiation backscattered and phase. The phase difference for the 2 coregistration of radar data sets for the identical area of interest are counted on a pixel by pixel base and an interferometer product would be produced by mix of both [12].

Phase unwrapping is the parameter that also need to be considered of interferometric processing and frequent problems of aliasing errors because of phase noise caused by under sampling and low coherence due to rates of locally high fringe [15]. There are several algorithms, including, minimum spanning tree, region growing and minimum cost flow for solution. They are statistical procedure that have been developed. In phase unwrapping prefers the region growing method [15] with disparity decomposition levels. Orbital refinement is required for DSM extraction after unwrapped phase [18].

The accuracy of elevation estimation is required from relation between phase difference and coherence. At the final step processing for interferometric to create surface elevation estimation, the phase values should be calculated into elevation estimation using phase to height algorithms of each pixel from interferogram. The result from height estimation should be convert to latitude and longitude for geographic coordinates and UTM coordinate system of the complex images are defined by x, y is planimetric coordinates and z is height estimation for geocoded terrain correction [3] [6].

2.2. DSM Validation

For the last step, the final DSM extraction from processing were validated by LiDAR for height estimation values of more precise LiDAR data located in the study area. We create some points randomly for plotting the elevation value as a comparison. Figure 2 shows the LiDAR image at district of pesanggrahan as the height of ground level the study area used for reference. The LIDAR data distribution will compare with the DSM extraction from processing.

We divided into three parts for areas validation, such as; river, road and building. Then we create 30 points random each area for get the values as validation. There are three statistical factor equation to calculate accuracy of DSM; root mean square error, linear error and absolute errors [10].

\[
|\text{Error } Z_0| = \frac{\sum|Z_0 - Z_i|}{n} \quad (1)
\]

\[
\text{RMSE}_z = \sqrt{\frac{\sum(\text{Error } Z)^2}{n}} \quad (2)
\]

\[
\text{LE95} = 1.96 \times \text{RMSE}_z \quad (3)
\]

where \(Z_0\) is elevation value from LiDAR, \(Z_i\) is elevation value from DSM and \(n\) which mean the number of measurements points.

3. Result and Discussion

In DSM processing, to obtain coherence map with high values we set 0.5 as coherence threshold. It means the number of pixels which have 49 percent matching are not process. Then in the result of DSM the pixels will be nan values. Based on our previous study about DEM [14], Spatial resolution should use in range 12 m to 24 m. In this research we set 12 m as multi-looked factor.

There are several things to consider during the processing. 1) coherence ranges from the pair radar images between 0 (which means, the phase is noise) and 1 (no noise at all), depending of the noise of the radar sensor, the errors that occurred on the previous interferometric steps which low accuracy in coregistration processing, 2) temporal baseline between the master and slave image, 3) systematic spatial, due to terrain topography, height differences and slopes, 4) acquisition geometry incidence angle
and side looking direction [7]. We set 0.5 as cross correlation threshold and Goldstein filtering method [16]. The DSM in Jakarta for urban area have some missing value on vegetation, due to [6] low coherence values generally occur in areas which covered by dense vegetation and water body. And good for urban and hilly areas.

For unwrapping phase step, region growing algorithms with decomposition level is three and coherence threshold is 0.5, that’s the parameters used for this study, based on [19]. In orbital refinement, the ground control points are requested during the process. We can set manually or automatically (if have points reference). More GCPs that is used will be better. Last step is terrain geocoding, the coordinate geographic system for final DSM should be in UTM WGS84 datum and geoid EGM 2008. We show the final result DSM extraction from TerraSAR-X in figure 3.

![Figure 3. DSM extraction from processing](image)

The quality assessment of DSM from processing will be validate by LiDAR. We divided into three parts area such as; road, building and river.

| Elevation of DSM (m) | Error Z (m) | RMSEz (m) | LE95 (m) |
|----------------------|-------------|-----------|----------|
| River                | 2.695       | 3.108     | 6.091    |
| Building             | 1.607       | 1.838     | 3.603    |
| Road                 | 2.350       | 3.040     | 5.958    |

Table 3. Accuracy Assessment of DSM and Validated by LiDAR

Table 3 illustrates the accuracy assessment from DSM extraction. As we can see the elevation on buildings area have high precision. Because on building, the percentage of range of coherence map between pair image using TerraSAR-X around 70% to 95% are coherence (the values from processing). According on table 3 for area in road and river have similarly accuracy. The number of elevations were dropped by low coherence area.

4. Conclusion
The final surface elevation model from TerraSAR-X and was validated by LiDAR has high precision. The elevation on the river and road area have similar value with vegetation area. This DSM can be use for surface model to get information like change detection. For next study, the DSM from this research will convert to DTM with elevation modelling and interpolation.
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