Filtering DSM extraction from Worldview-3 images to DTM using open source software

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Abstract. Today, the Indonesia one map policy has encouraged for producing maps up to scale 1/5,000 – 1/10,000. Therefore, all efforts to accelerate large-scale map production are still needed. One of the challenges is for producing DEM (Digital Elevation Model). DEM data extraction from high-resolution optical satellite imagery is an efficient choice for the production of large-area DEM. This study uses Worldview 3 stereo ready images for DSM (Digital Surface Model) Extraction. Although the DSM data have a high resolution 30cm x 30cm, unfortunately, the DEM extraction techniques from optical images produce DSM (Digital Surface Model) data instead of DTM. While topographic maps generally use DTM data instead of DSM. So, the goal of this study is to use an appropriate procedures method in Open-Source (OS) software towards the generation of Bare-Earth data by filtering DSM. The OS software is SAGA-GIS that it is can be used for any point cloud data. The quality of DTM generated by SAGA-GIS is evaluated by visual interpretation from Worldview 3 orthoimage itself. A good filtering result will remove the non-terrain point. Some independent check point used to evaluate the error in elevation. The error in elevation still less than 2 pixels. Final product is a high resolution DTM which has 30cm x 30cm grid spacing.

1. Introduction

In year 2016, the Presidential Regulation of the Republic of Indonesia No. 9 of 2016 has concerning the Acceleration of the Implementation of the One Map Policy at the Level of Accuracy of Maps Scale 1/50.000 [1]. On recently progress, the map scales up to 1/10.000-1/5.000 are more needed in many sector implementations. The existing base map (topographic) scale 1/5.000 is still very limited. Therefore, all efforts to accelerate large-scale 1/10.000-1.5.000 map production are still needed. There are many researches has used of Very High-Resolution Satellite (VHRS) imagery technique for producing a base map (see [2], [3], [4], [5]). This study uses Worldview 3 stereo ready images that has 30cm x 30cm spatial resolution.

One of the challenges for base mapping is to produce a detail DEM (Digital Elevation Model) that represent Terrain topography also called DTM (Digital Terrain Model). Regarding a wide-area coverage, the DEM data extraction from VHRS imagery is an efficient choice for the production of wide-area DEM. Although the Worldview 3 imagery have a high resolution 30cm x 30cm, unfortunately, the DEM extraction techniques from optical images produce DSM (Digital Surface Model) data instead of DTM. So, choosing filtering procedure to produce a high resolution DTM from VHRS optical imagery DSM extraction is still an open problem.

There are some open source Geographic Information Software (OS-GIS) for processing point cloud data (ex. Quantum GIS, SAGA-GIS). One of the OS-GIS for point cloud software is SAGA-GIS which processing LAS file. This SAGA-GIS software has some Bare-Earth filtering features. So, the goal of this study is to define an appropriate procedures method in Open-Source (OS) software towards the generation of DTM by filtering DSM. A good DTM data should have non-terrain free data. The evaluation of the DSM filtering quality can be done by visual interpretation. This study uses a worldview
3 orthoimage itself to evaluate the DTM quality. The appearance of contour line is used to evaluate the non-terrain manmade objects removal also.

2. Datasheet Description

2.1. Test Area Study
The study area is in the Tasikmalaya district. This area has mountainous landscaping consisting of residential areas, paddy fields, and vegetation forests. The surface height varies between 422m and 758m above sea level. There is a minor cloud coverage area in the image also. Figure 1 shows the location and terrain conditions represented by the digital surface model. Coverage area is 4.62 km x 5.31 km with coordinates boundary 7° 11’ 39.5254’S - 7° 14’ 34.1123’S; 108° 09’ 24.1305”E - 108° 11’ 55.9795”E.

![Figure 1. Study area with mountainous landscape at Tasikmalaya district.](image)

(R) residential area, (P) paddy fields area, (V) Vegetation area, and (C) Cloud.

2.2. Image Data and Reference Point
In General, Worldview-3 imagery data is distributed at five different levels, i.e. Basic 1B, Basic Stereo Pairs, Standard 2A, Ortho-Ready Standard (OR2A) and Orthorectified. This research uses an OR2A product level (see Table 1) with spatial resolution 0.3m. The OR2A images are products which have been projected to an average elevation and with no topographic relief applied, making it suitable for geometric correction or custom Orthorectification. This level product has auxiliary data including ephemeris, 3rd-order RFM coefficients of each image also that it is provided as separate files. The off-nadir angle of both images is almost similar. Regarding the B/H ratio factor, this angle is not too good for extracting elevation. However, it is good for automation processing due to a high cross correlation between two images.

Although the image has Rational Polynomial Coefficient Model, it is still needing some local control point to compensate the systematic error in position due to datum coordinates issue. A Six well-known ground control points are used as GCP (Ground Control Point) to refine the RPC model to fit the local coordinate datum. While others five point used as Independent Check Point. All of the check points have taken from terrestrial survey method. The UTM Zone 49S map projection is used for coordinate system.
Table 1. Datasheet Worldview-3 level Stereo OR2A.

| Left Image | Right Image |
|------------|-------------|
| <GENERATIONTIME>2016-01-21T17:20:41.000000Z | <GENERATIONTIME>2016-01-21T17:22:09.000000Z |
| <BANDID>P | <BANDID>P |
| <PANSHARPENALGORITHM>None | <PANSHARPENALGORITHM>None |
| <PRODUCTLEVEL>Stereo OR2A | <PRODUCTLEVEL>Stereo OR2A |
| <RADIOMETRICLEVEL>Corrected | <RADIOMETRICLEVEL>Corrected |
| <MEANOFFNADIRVIEWANGLE>2.290000000000000e+01 | <MEANOFFNADIRVIEWANGLE>2.670000000000000e+01 |

3. Methodology
The methodology is arranged so that objectives can be achieved effectively. The purpose of this study is to evaluate the capabilities of SAGA-GIS software towards the generation of Bare-Earth data by filtering DSM. The workflow for DSM extraction from WV-3 stereo-images and accuracy evaluation shows in Figure 2.

**Figure 2.** Procedure for deriving DTM by filtering DSM from Worldview-3.

The most important steps are addressed as follows:
1) The Automatic tie points (TPs) extraction and Image point measurement of GCPs is more reliable if the cross correlation between image is rather high (i.e. it has similar off-nadir angle). Meanwhile, the GCPs are very essential to compensate the systematic error of Rational Polynomial Function to achieve a desirable local coordinate system. Image point measurement of GCPs is performed semi-automatically, and also, TPs are extracted automatically by image matching of stereo-pairs image, considering the geometric constraints and geometric invariant features. The Bundle Block adjustment computation can show the precision of the model. In general, standard error less than 2 pixel is quite enough for future processing step.
2) The DSM (Digital Surface Model) extraction process start with forming epipolar images geometry. A good epipolar geometry can be showed by parallax y-axis close to zero. Then, image matching algorithm used to find x-axis parallax values as an input for height differences computation. The image matching algorithm with area-based matching have some weaknesses
that make DSM produce noise or spike value. One of the conditions is an image that has homogeneous texture (i.e., cloud, water body, rooftop, paddy field, desert, etc.). In non-textured objects, the image matching operator can be wrong.

3) The DTM (Digital Terrain Model) formation process start with noise point removal (see [6]). Since the 3-D points automatically extracted by image matching, in some objects produce wrong value (Spike or Pit). It is easy to find spike or pit as wrong elevation values. By implementing a sink removal module (see [7]), the spike and pit data can be removed. Furthermore, some object is not terrain objects also. So, it needs a filtering process to remove a non-terrain data from DSM. An empty area than filling by interpolation algorithm (see [8], [9]).

4. Result and Discussion

4.1. Noise Point Removal

The DSM extraction process produce a full spatial resolution grid spacing 0.3m x 0.3m (see Figure 1). In some homogenous textured objects such as paddy field and water body there are spike and pit error (see Figure 3). The sink removal module in SAGA-GIS terrain analysis pre-processing can reduce this error significantly. Then, the removal data area is filled by linear interpolation. The noise points show in paddy field, water body and some rooftop objects. It can be seen that even after point removal operation, the non-terrain object (i.e. houses, trees vegetation) still exist.

![Figure 3. Result from noise point removing by sink removal module.](image)

4.2. Visual Evaluation

In general, an elevation information in Base map should represent terrain data. So, a non-terrain data from DSM extraction should be removed, then an interpolation algorithm should be implemented to fill the missing data. Figure 4 shows the result of implementing Slope-Based DTM filtering [9] and Module Multilevel B-Spline Interpolation [10] to filling the empty area.
Based on visual analysis, several statements can be taken as follow:
1) DSM filtering procedure is working for remove some non-terrain data dominantly. Unfortunately, not all of non-terrain data can be removed. There is still a minor data that can produce a bull-eyes effect in the contour line. So, for removing a non-terrain data completely, it needs to run iteratively with try and error also.
2) In open area such as paddy field area, the DSM filtering procedures give the best result in contrast with the houses area that give the worst output. It should be notes that the filtering parameter value cannot working well in all type landscape area.
3) The noise removal procedure should be applied after DSM Filtering process. Then, the DSM Filtering rerunning again for the second phase. The final DSM filtering assumed represent to DTM product.

4.3. Check Point Evaluation
The final DSM Filtering are evaluated with some check points also. Table 2 shows the elevation differences between Check Point and its correspondent at DTM product. Mostly, the independent check points locate at resident area which is not the best as an open area. Comparing with the worldview-3 spatial resolution, the average elevation error almost close to 2 pixels. This error still acceptable for some application that need sub-meter accuracy. This error is acceptable for producing map scale 1/10,000 also.

| Point | X       | Y       | Z (m)   | Z ICP (m) | Diff. (m) |
|-------|---------|---------|---------|-----------|-----------|
| 1     | 189275.51 | 9200834.23 | 469.463 | 471.246   | 1.783     |
| 2     | 187109.705 | 9200945.082 | 536.931 | 536.107   | -0.824    |
| 3     | 187198.017 | 9198539.024 | 481.74  | 483.093   | 1.353     |
| 4     | 189671.486 | 9198728.781 | 442.124 | 443.126   | 1.002     |
| 5     | 187398.033 | 9200043.43 | 509.806 | 509.371   | -0.435    |

**Average** 0.576
**S.Dev.** 1.143
5. Conclusion
This paper shows some procedures for producing DTM (Digital Terrain Model) from filtering DSM that have been extracted from worldview-3 imagery. There are some important processes should be notes which are noise point removing (spike and pit) and DSM filtering. There are still some minor non-terrain points event the filtering process has done. So, Filtering process should be repeated until the non-terrain point completely removed. For the future, it is need to study the most optimal interpolation algorithm for filling the non-terrain point that has been removed.

6. References
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