IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

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To cite this article: A Setiyoko and A M Arymurthy 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **88** 012021

Accuracy Analysis of DEM Generated from Cokriging Interpolators

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Abstract. DEM as a representation of the earth's surface has many functions for spatial analysis. DEM can be produced from several kinds of techniques such as satellite technology stereo optical or radar technology. Problems when using the optical stereo data is at the high point density level that is not distributed evenly. In regions with homogeneous character, the height point is becoming sparse. This will affect to DEM accuracy. In order to solve the problem, performing fusion techniques using interpolation method cokriging involving data points ALOS PRISM and SRTM height point was conducted. The sparse height point derived from ALOS PRISM on some object is expected to be enhanced by using SRTM data. There were several aspects to enhance the accuracy of DEM-derived from this process: the character of topography, land cover types, density in height point of the data and the precise type of interpolation method used.

1. Introduction

Digital Elevation Model (DEM) is very important for various purposes including geology, hydrology, environmental modeling and urban planning [1]. DEMs also support the study of rainfall and earthquake-induced landslides [2]. DEM is needed in a large number of applications, starting from virtual globes and visualization to engineering and environmental planning [3]. DEM serves as an input for much spatial analysis [4]. DEM and its derivation such as slope and aspect were very important input for spatial analysis, particularly for forest fire vulnerability. Rogeau and Armstrong conducted a research to quantify the effects of elevation, aspect, slope as variables on probabilities of burning [5]. On the other side, satellite image orthorectification process requires DEM data to correct error affected by image perspective (tilt) and relief (terrain) effects [1].

DEM as a representation of height information of landscape can be generated from multisource, such as stereo optical imagery, Synthetic Aperture Radar (SAR), land surveying, airborne light detection and ranging (LIDAR) [3]. Older methods of generating DEMs often involve interpolating digital contour maps that may have been produced by direct survey of the land surface. This method is still used in mountain areas, where interferometry is not always satisfactory. DEM generated from Cartosat-1 stereo data has a value of RMSE ranging from 1.29 m to 2.96 m [6].

The quality of a DEM is a measure of how accurate elevation is at each pixel (absolute accuracy) and how accurately is the morphology presented (relative accuracy). Several factors play an important role for quality of DEM-derived products: (1) terrain roughness; (2) sampling density (elevation data collection method); (3) grid resolution or pixel size; (4) interpolation algorithm; (5) vertical resolution; and (6) terrain analysis algorithm [7]. Based on the previous research it was observed that ordinary kriging is the best interpolator for Cartosat-1 DEM [6]. It has been observed also that interpolation method with the least error is universal kriging and interpolation method with the highest error is global polynomial in generating IRS 1C DEM [8]. In some specific objects, height points are not well generated. Lack of height point usually occurs in the low frequent object where the slope of the terrain is very high [9].

In order to solve the problem, [9] have conducted research robust stereo image matching for spaceborne imagery concluded that experimental results with Cartosat-1 images indicate that the aspect-based correlation and blunder detection works very efficiently and effectively in stereo image matching. There is various research have been conducted in DEM fusion. Papasaika *et al* have conducted research in Fusion of Digital Elevation Models using Sparse Representations and concluded that the DEM fusion achieved up to 43% improvement in RMSE [3]. Schindler *et al* have conducted research in Improving Wide-Area DEMs through Data Fusion – Chances and Limits [1]. The research has an output that the experiments confirm significant improvements are possible by fusion of existing DEMs – in the ALOS + SPOT case the RMSE was reduced by 29%. There are various alternate methods to solve the problem by using geostatistical theory. Common techniques are probabilistic interpolators: simple kriging, ordinary kriging, universal kriging, indicator kriging, probabilistic kriging, disjunctive kriging, cokriging and also deterministic interpolators: inverse distance weighted (IDW), global polynomial, local polynomial, radial basis functions (RBF) written by [10]. Setiyoko and Kumar have conducted research to interpolate height point derived from stereo imagery using both probabilistic interpolators and deterministic interpolators [6]. It’s concluded that cokriging method as the probabilistic method has better accuracy.

Another method used to interpolate point is a multiple-point geostatistical simulation (MPS) that was conducted by [11] to interpolate bathymetry data. Tang *et al* proposed a FILTERISM method that combined traditional geostatistics and the MPS for the purpose of image fusion and super-resolution enhancement which was used to downscaling remote sensing data applied only to image fusion of multispectral and panchromatic bands [12]. Tang *et al* then improved the method as improved FILTERISM by combining with a geostatistic approach to derived digital elevation data fusion using multiple-point geostatistical simulation [13]. Even there was view research in the development of geostatistic, to apply cokriging on DEM interpolation based on multi-point is still challenging because it has many method setting to be implemented. The issue in fitting variogram, the best setting of neighborhood searching are the problem to be solved. Because to fit the best variogram requires an understanding of the assumptions in the underlying theory of random processes on which geostatistics is based [14]. In order to get the best result, understanding trend and characteristic of the data used are very critical to choose the best variogram and parameters of the searching neighborhood.

In this research, we still conducted cokriging interpolation technique to fuse ALOS PRISM height points and SRTM height points by applying best fitting variogram and searching neighborhood by considering trend and character of study area topographic. This research project is aimed to calculate the accuracy of DEM generated from various cokriging interpolations by using two kinds of height points sources: ALOS PRISM and SRTM. Combination both data in cokriging interpolation should increase the accuracy of DEM-derived.

2. Cokriging

Cokriging uses more than one variable types [15], compared to kriging that only uses one variable type. Models based on more than one variable of interest form the basis of cokriging. Cokriging could be used as a tool for image fusion [16]. Cokriging could predict unknown point by calculating the main variables of $Z(s)$, both autocorrelation of $Z(s)$ and cross-correlation between $Z(s)$ and other type of variables would help to make a better predictions [15]. Cokriging is more complex compared to kriging. Basically cokriging is based on kriging theoretical term. Kriging requires a semivariogram modeling including values for the parameters: nugget, sill, and range. The semivariogram is defined as [15]:

$$Y(s_i, s_j) = \frac{1}{2} var(Zs_i - Zs_j) \tag{1}$$

where var is the variance.

Ordinary cokriging expressed in the following simple mathematical formula [15]:

$$Z_1(s) = \mu_1(s) + \varepsilon_1(s) \qquad (2)$$
$$Z_2(s) = \mu_2(s) + \varepsilon_2(s)$$

where $Z_1(s)$ and $Z_2(s)$ are the variables of interest, decomposed into a deterministic trend $\mu_1(s)$ and $\mu_2(s)$ which have random autocorrelated errors form $\varepsilon_1(s)$ and $\varepsilon_2(s)$. There would be autocorrelation for each of them and cross-correlation between them. Variations on this formula form the basis for all of the different types of cokriging. The trend can be a simple constant; that is, $\mu(s) = m$ for all locations s. Understanding different type of cokriging seen in Table 1 [15].

Table 1. Cokriging Methods.

No	Method	Definition
1	Ordinary Cokriging	If $\mu_1(s)$ and $\mu_2(s)$ are unknown, then this is the model on which Ordinary Cokriging is based.
2	Simple Cokriging	Whenever the trend is completely known (i.e., all parameters and covariates known), whether constant or not, it forms the model for Simple Kriging.
3	Universal Cokriging	Trends that vary, and where the regression coefficients are unknown, form models for Universal Kriging.
4	Disjunctive Cokriging	The general unspecified transformations of the $Z(s)$, namely $f_i(Z(s_i))$ or the i^{th} variable can be made. The Disjunctive Cokriging predictor is processed by performing functions of variables to predict at location s_0.

3. Methodology

Location of study area, lies in city of Bandung, West Java, Indonesia, having boundary coordinates 761716.36 E – 791911.41 E and 9255543.35 S – 9216181.95 S in the datum of WGS (World Geodetic System) 84 and the projection system is UTM (Universal Transverse Mercator) as seen in Figure 1, which has both plain and hilly area with covered by multi type of land cover objects.

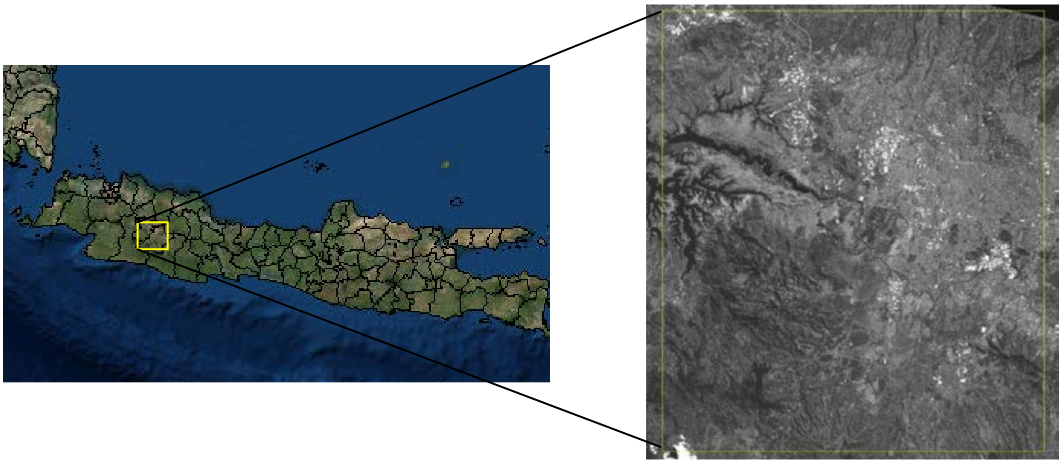
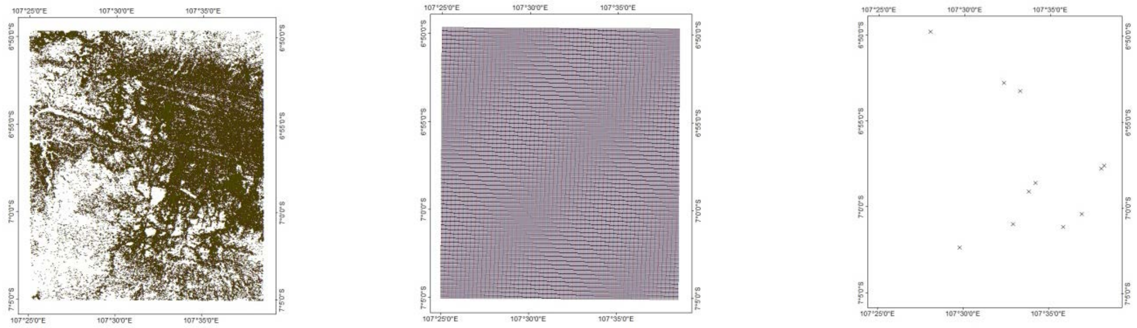


Figure 1. Study area of research experiment.

Data used in this research project are height points generated from ALOS PRISM stereo data and height points generated from Shuttle Radar Topography Mission (SRTM) seen in Figure 2. To validate the generated DEMs, high precision height points are used. Details of ALOS PRISM height points: generated from stereo panchromatic data; spatial resolution 2.5 m at nadir, observation date August 7th 2006, ellipsoid/datum EGM96, projection system UTM, zone no=48. Details of SRTM height points: generated from SRTM raster data version 4.1; horizontal datum WGS84; vertical datum EGM96 (Earth Gravitational Model 1996) ellipsoid; Spatial Resolution 3 arc-seconds for global coverage (90 meters); C-band Wavelength 5.6 cm. While high precision Points as reference points are the national base coordinate system used for national mapping, with the detail information as follows: Number of points 11 points, Horizontal datum WGS 84, Vertical datum EGM96.



(a) (b) (c)

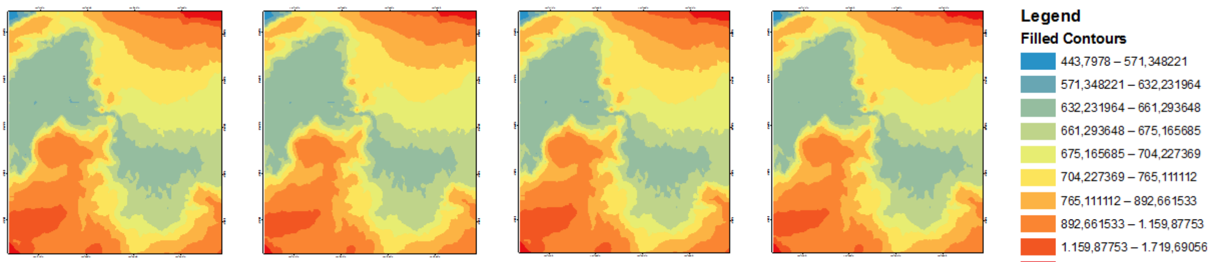
Figure 2. Height Points: (a) ALOS PRISM, (b) SRTM (c) Reference.

ALOS PRISM height points which contained 305882 points were generated from the interior and exterior orientation process based on satellite photogrammetric method. ALOS PRISM height points weren’t well distributed in the study area. Dense points were located in high frequent objects such as buildings, road or settlement area, while sparse points found in a homogeneous object such as paddy field, forest, water body where matching points hardly to be generated in satellite photogrammetric processing. SRTM height points were derived from raster format of DEM by conducting raster to point processing. SRTM height points contained 83739 height points which were the same as the pixel number of the raster of the study area. One height point was a representation of each pixel value of DEM SRTM.

Both ALOS PRISM height points and SRTM height points were fused by implementing cokriging interpolation to generate DEM. ALOS PRISM height points defined as dataset one and SRTM height points defined as dataset two. By using module geostatistical analyst in ArcMap software, four techniques of cokriging (universal cokriging, ordinary cokriging, simple cokriging, and disjunctive cokriging) were applied. Four generated DEMs were expected to be generated from each technique. Accuracy analysis would be conducted by calculating a residual error based on the root mean square (RMSE) method of height information derived from interpolation method that has been applied to the datasets. In this analysis, reference height points were used as validation.

4. Result and Analysis

After performing interpolation techniques, four DEMs were generated. There are DEM derived from ordinary cokriging method (DEM OC), DEM derived from simple cokriging method (DEM SC), DEM derived from ordinary universal method (DEM UC), and DEM derived from ordinary disjunctive method (DEM DC) seen in Figure 3.



(a) DEM OC (b) DEM SC (c) DEM UC (d) DEM DC

Figure 3. DEMs generated from cokriging interpolation method.

In this experiment, analysis is conducted by performing RMSE quantitative analysis and visual comparation. General visualization of the four DEMs is resemblance one to another. In general, there is no difference when seen visually. Even so, if considered in more detail in some places there is a difference. DEM OC and UC there are similarities visually, while DEM SC and DC look difference. After validation analysis using height reference points, the calculation results obtained residual error for each DEM, as shown in Table 2.

Table 2. Residual Error (m) of Generated DEMs.

No	Reference Point	Character	Land Cover	ALOS Height Point	DEM UC	DEM OC	DEM SC	DEM DC	Average Residual Error
1	303	Plain	Settlement	Dense	1.50	1.50	1.70	0.92	1.41
2	172	Plain	Settlement	Dense	3.90	3.90	3.42	4.25	3.87
3	182	Plain	Settlement	Sparse	7.99	7.99	7.14	7.61	7.68
4	310	Plain	Settlement	Dense	5.70	5.70	5.38	6.03	5.70
5	045	Plain	Settlement	Dense	4.69	4.69	9.75	7.15	6.57
6	007	Plain	Settlement	Dense	2.49	2.49	2.14	2.93	2.51
7	237	Plain	Settlement	Dense	0.75	0.75	6.64	3.08	2.81
8	029	Plain	Settlement	Dense	4.18	4.18	3.44	4.39	4.05
9	028	Plain	Settlement	Dense	1.49	1.49	1.15	1.43	1.39
10	0282	Hilly	Plantation	Sparse	12.02	12.02	0.99	8.81	8.46
11	0283	Hilly	Lake Area	Dense	3.64	3.64	5.75	3.01	4.01
	Average Residual Error				4.40	4.40	4.32	4.51	

The accuracy of generated DEMs depends on character of the topographic surface, landcover type, density of height point, and interpolation method. Hilly surface affected the accuracy of the DEM, seen at the reference point number 0282, where the average of the highest residual error, which is 8.46 m. While in the plain area have a relatively lower error and the lowest at 303 points, with an average of 1.39 m. When considering the influence of the type land cover at the reference point in the plantation area has a residual error is higher than other regions, although there are variations in the residual error settlement but remained relatively smaller which is also influenced by the density of the ALOS PRISM height points. As seen reference points 182 and 0282 where the height point is sparse, residual error is relatively higher compared to other points. Simple cokriging method was resulting a better interpolated DEM, as seen in Table 2, DEM SC has a smallest average residual error, 4.32 m.

In order to see the connection between the residual errors every cokriging method used, in this study, the T-Test Analysis across methods was applied. The asymp. Sig. (2-tailed) value of the residual error between each method is higher than 0.05, so that each pair did not have a significant difference.

5. Conclusion

In general, the accuracy of the DEM from ALOS PRISM fusion product height points with SRTM height points by using interpolation method cokriging depends on several factors such as the character of topography, land cover types, densities in height point of the data and the precise type of interpolation method used. In this study, high precision of interpolated value is obtained at reference point 028 which is plain located on settlement area with a dense ALOS PRISM height point. While the highest accuracy is obtained at the reference point 237 with the same character with 028 points, which is obtained by using Universal Cokriging or Ordinary Cokriging. While the highest residual errors obtained at reference point 0282 which is located on hilly and covered by plantation land cover and contained sparse ALOS PRISM height point. Therefore land cover type could be added as a factor that affects the quality of DEM-derived products, as additional the several factors that play an important role in DEM quality [7]. It's occurred particularly for DEM generated from stereo imagery based on this research experiment. This additional factor of DEM error is the contribution for the research.

Further research will be done by conducting a study on the problem to increase the number of height points of a region mainly on homogeneous land cover.

References

[1] K. Schindler, H. Papasaika-hanusch, S. Schütz, and E. Baltsavias, “Improving Wide - Area DEMs Through Data Fusion - Chances and Limits,” pp. 3–14.
[2] J. Iwahashi, I. Kamiya, and H. Yamagishi, “Geomorphology High-resolution DEMs in the study of rainfall- and earthquake-induced landslides : Use of a variable window size method in digital terrain analysis,” *Geomorphology*, vol. 153–154, pp. 29–38, 2012.
[3] H. Papasaika, E. Kokiopoulou, E. Baltsavias, K. Schindler, and D. Kressner, “Fusion of Digital Elevation Models Using Sparse Representations,” *U. Stilla al.*, pp. 171–184, 2011.
[4] P. C. Kyriakidis, A. M. Shortridge, and M. F. Goodchild, “Geostatistic for conflation and accuracy assesment for digital elevation models,” *Int. J. Geogr. Inf. Sci.*, vol. 13, no. 7, pp. 677–707, 1999.
[5] M. Rogeau and G. W. Armstrong, “Forest Ecology and Management Quantifying the effect of elevation and aspect on fire return intervals in the Canadian Rocky Mountains,” *For. Ecol. Manage.*, vol. 384, pp. 248–261, 2017.
[6] A. Setiyoko and A. Kumar, “COMPARISON ANALYSIS OF INTERPOLATION TECHNIQUES FOR DEM GENERATION USING CARTOSAT-1 STEREO DATA,” *Int. J. Remote Sens. Earth Sci.*, vol. 9, no. 2, pp. 78–87, 2012.
[7] A. M. Elmoustafa, H. N. Farres, and M. M. Elfawy, “Effect of Elevation Data Accuracy on Storm Drainage Schemes , Lagos , Nigeria,” *Nat. Resour.*, vol. 6, pp. 433–441, 2015.
[8] A. Setiyoko, “Analysis of spatial interpolation techniques for DEM generation using IRS-1C data,” in *34th Asian Conference on Remote Sensing 2013, ACRS 2013*, 2013, vol. 2, pp. 789–794.
[9] V. N. Radhika, B. Kartikeyan, B. Gopala Krishna, S. Chowdhury, and P. K. Srivastava, “Robust stereo image matching for spaceborne imagery,” *IEEE Trans. Geosci. Remote Sens.*, vol. 45, no. 9, pp. 2993–3000, 2007.
[10] P. A. Burrough and M. Rachael A., *Principles of Geographical Information Systems*, no. January 1998. OXFORD UNIVERSITY PRESS, 1998.
[11] S. K. Jha, G. Mariethoz, and B. F. J. Kelly, “Bathymetry fusion using multiple-point geostatistics: Novelty and challenges in representing non-stationary bedforms,” *Environ. Model. Softw.*, vol. 50, pp. 66–76, 2013.
[12] Y. Tang, P. M. Atkinson, and J. Zhang, “Downscaling remotely sensed imagery using area-to-point cokriging and multiple-point geostatistical simulation,” *ISPRS J. Photogramm. Remote Sens.*, vol. 101, pp. 174–185, 2015.
[13] Y. Tang, J. Zhang, L. Jing, and H. Li, “Digital Elevation Data Fusion Using Multiple-Point Geostatistical Simulation,” *IEEE J. Sel. Top. Appl. EARTH Obs. Remote Sens.*, vol. 8, no. 10, pp. 4922–4934, 2015.
[14] M. A. Oliver and R. Webster, “A tutorial guide to geostatistics: Computing and modelling variograms and kriging,” *Catena*, vol. 113, pp. 56–69, 2014.
[15] K. Johnston, J. M. Ver Hoef, K. Krivoruchko, and N. Lucas, “ArcGIS 9 ® Using ArcGIS Geostatistical Analyst,” in *ESRI*, vol. 5, no. 2, 2001, pp. 131–166.
[16] N. Memarsadeghi, J. Le Moigne, N. Gsfc, and D. M. Mount, “Image Fusion Using Cokriging,” *IEEE*, pp. 2–5, 1999.

Acknowledgments

This project was supported by Faculty of Computer, University of Indonesia and Remote Sensing Technology and Data Center, LAPAN Indonesia.