COMPARISON ANALYSIS OF INTERPOLATION TECHNIQUES FOR DEM GENERATION USING CARTOSAT-1 STEREO DATA

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Abstract. Digital Elevation Model (DEM) can be generated using several techniques such as photogrammetric technique, interferometry, Lidar, etc. In photogrammetric technique, a DEM generation using stereo images, accuracy of generated DEM is also dependent on interpolation techniques. The process of interpolation is conducted to generate DEM as a continuous data from the point map that contained height information as a discrete data. In this research, point map was extracted from Cartosat-1 stereo image and from geodetic single frequency GPS in differential mode. Different interpolation techniques were applied on these data sets with different combination within these data sets. In this study, analysis of DEM interpolation was conducted with deterministic interpolators such as inverse distance weighted (IDW), global polynomial, local polynomial, and radial basis functions (RBF); and probabilistic interpolators such as simple kriging, ordinary kriging, universal kriging, indicator kriging, probabilistic kriging, disjunctive kriging, and cokriging. The accuracy of generated DEMs through different interpolation techniques were evaluated with ground point data collected from geodetic single frequency GPS in differential mode. Based on the analysis, the range error of DEMs generated was between 1.29 m to 2.96 m. Interpolation method with the least error was ordinary kriging using point map data and GPS points, while the highest error was obtained from global polynomial method.

Keywords: *DEM Generation, interpolation, kriging, point height*

1 INTRODUCTION

Recent technology development enables DEM generation using several techniques such as digital photogrammetric, interferometry, Lidar, etc. In all the different techniques of DEM generation, accuracy of generated DEM is also dependent on interpolation techniques. Interpolation is the procedure of predicting the value of attributes at unsampled sites from measurements made at point locations within the same area or region (Borrough *et al.*, 2001). Spatial interpolation is the process of using points with known values to estimate values at other points (Chang and Kang-tsung, 2006). Interpolation is used to convert data from point observations to continuous fields so that the spatial patterns sampled by these measurements can be compared with the spatial patterns of other spatial entities. Interpolation process or in specific term is spatial interpolation will proceed the estimation of the value of properties at unsampled sites within the area covered by existing observations using geostatistic method. Geostatistic is a method of predicting the values between known values using statistical approaches (Srivastava, 2006). Geostatistic are applied in many fields such as environmental contamination (Henshaw *et al.*, 2004), dynamics of organic matter distribution (Nogueira *et al.*, 2001), and spatial interpolation of rainfall (Goovaerts, 2000).

In this research, geostatistic was applied to interpolate the value of height between the conjugate points derived from stereo images. The spatial interpolation itself was placed in the last step of creating DEM after the points of height was already formed. The spatial interpolation in generating DEM generally using the default model in the processing system or using common method of interpolation, such as bilinear interpolation for example (Murthy *et al.*, 2008). In this research work, the study and analysis of DEM interpolation were conducted using the existing and new methods of interpolation techniques i.e., Kriging, Weight Average, and CoKriging, etc.

Spatial interpolation divided into 2 methods that were deterministic and stochastic. Deterministic method used mathematical formula to form weighted averages of nearby known values, and also provided no assessment of errors of predicted values. Stochastic method used weighted averages and also probability models to make predictions, the assessment of prediction errors were also offered with estimated variances (Chang and Kang-tsung, 2006). Some example of deterministic interpolators are inverse distance weighted (IDW), global (trend surface), local polynomial, and radial basis functions (RBF). While, example of probabilistic interpolators are global (regression), simple kriging, ordinary kriging, universal kriging, indicator kriging, probabilistic kriging, disjunctive kriging, and cokriging.

The technology in stereo data acquisition, introduced by Indian Space Research Organization (ISRO) is the first generation of Cartosat satellite. Cartosat-1 has the capability to acquire stereo image in a long track acquisition with the spatial resolution of 2.5 m, having very small temporal differences in both the scene (Krishnaswamy, 2002). In this research, point map that contained height information was generated from Cartosat-1 stereo data and from geodetic single frequency GPS in differential mode. Different interpolation techniques were applied on these data sets with different combination within these data sets. This study was conducted to analyze the interpolation techniques for deriving DEM from stereo data and to show level of accuracy for each interpolation technique in generating the interpolated continuous surfaces. The main research problem in the form of question was that how much the accuracy of each DEM generated from many methods of interpolation techniques. The data used in this work were from 3 sources i.e., Cartosat-1, point map, and GPS points. The combination of data for each type of interpolation then created DEM to be analyzed using reference GPS data that measured accurately. Based on the research problem, the objective of this research was to analyze the accuracy of generated DEMs with respect to the interpolation methods applied.

2 MATERIALS AND METHOD

The study area in Figure 1 is moderately hilly, lies in the northwest part of Dehradun, Uttaranchal State, India, having boundary coordinates 78°00'36.06"E-78°02'37.26"E and 30°24'14.91"N- 30°21'46.98"N. The study area has the altitude of 582 – 1003 m, consist of various land cover objects such as forest, buildings, rocks, etc., but dominated by forest cover. Data used in this study consisted of:

- Point map generated from Cartosat-1 stereo data, with the detail information is as follows:
  - 2 pair stereo panchromatic data named PAN_AFT and PAN_FORE,
  - Path/Row: 0526/0258,
  - Date of Pass: 2^{nd} of October 2005,
  - Ellipsoid/Datum: Everest/Indian 1954.
- GPS points obtained from field measurement.
- Accurate points measured using GPS receiver for accuracy assessment analysis.

The methodology adopted for this research work is shown in Figure 2 with the general steps consists of data preparation, DEM interpolation, and analysis. Data preparation is needed in order to make the data ready to be interpolated based on the experiment methodology of this research and fulfill the specification such that all data are in one datum system, covered the same area, and collected into similar format. First pre-processing of the data was done to derive point map and GPS points.

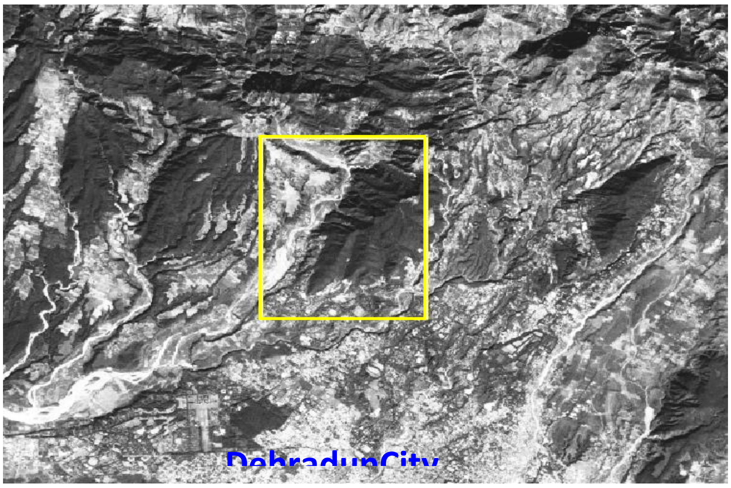


Figure 1. Study Area of Research (Subset)

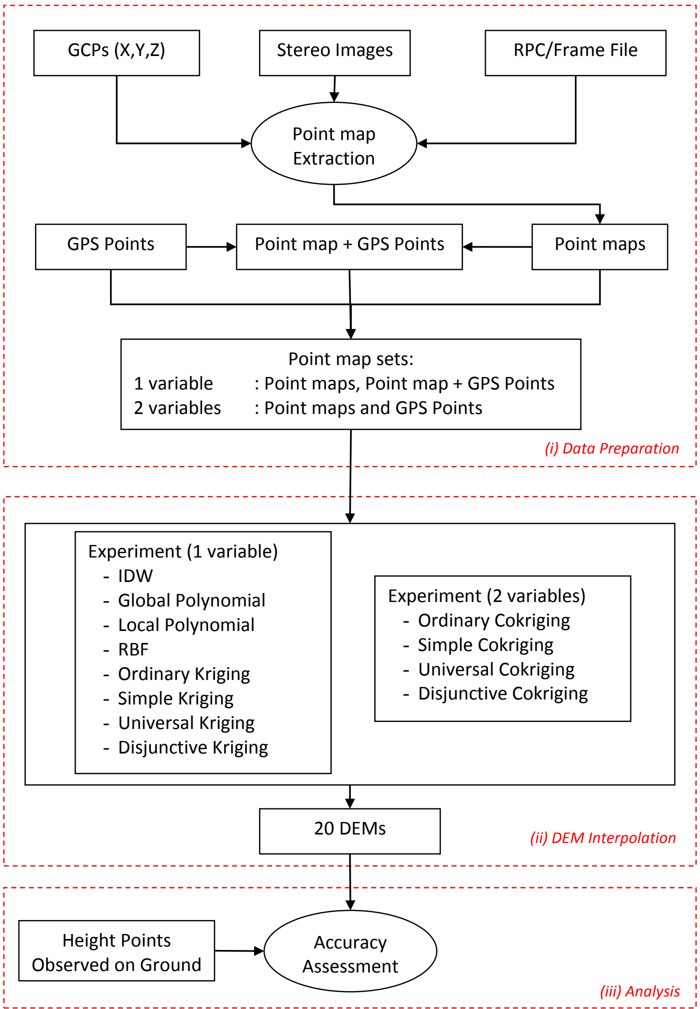


Figure 2. Research methodology

The research method was developed based on previously studies (Niu *et al.*, 2006 and Cheng *et al.*, 2001). The point map extraction from Cartosat-1 data in Figure 2 was consisted of five main steps i.e., sensor model setup, interior orientation, external orientation, block triangulation and auto tie collection with GCPs, and DEM extraction.

First, model was setup by setting the sensor characteristics used for imaging and also by setting the horizontal and vertical datum. The model of sensor was rational functions for Cartosat-1, and the horizontal datum was Indian 1954 with Everest as spheroid and vertical datum was based on WGS 84 for all data. The next step was orientation both interior orientation and exterior orientation. The interior orientation was done using sensor file, RPC for Cartosat-1. The process of exterior orientation was then done using sensor file from interior orientation and ground control points (GCPs) in the forms of latitude, longitude, and height taken using differential GPS measurement that covered both stereo pair images. GCPs were then placed in the conjugate points on two images to process the block triangulation and auto tie collection. The block triangulation report should show the least RMS error so the process can be accepted for next step. Finally, the DEM extraction was then processed to generate point map with the pixel size with respect to the spatial resolution of stereo data.

The GPS measurement used two single frequency GPS receivers. One receiver for the base and the other was rover that moved along the survey points. To acquire the GPS points the stop and go technique was chosen. The points were measured randomly at the test site of the locations of measurement and were chosen in the open area to receive the most accurate possible of coordinates in latitude, longitude, and height. The horizontal datum was WGS 84 and vertical datum above ellipsoid using vertical datum also WGS 84. Then the coordinate transformation of horizontal datum was processed from WGS 84 into Indian 1954. Accurate GPS points for accuracy assessment were selected using differential method of measurement to achieve the high accurate coordinate in three dimensional (X, Y, Z). They were taken in longer time and randomly in different places from the GPS points for interpolation mentioned above.

Data preparation was needed before conducting the interpolation experiment. After preprocessing data for this work, three data sets were generated i.e., Cartosat-1, point map, and GPS points that have been set into one coordinate system as mentioned before. In this research, different combinations of data sets were taken for different interpolation methods. The IDW, global polynomial, local polynomial, RBF, and kriging methods were based on 1 variable, while cokriging method used 2 variables. The use of 1 variable based on the requirement of the interpolation methods mentioned and the use of 2 variables for cokriging justified by Meer (1993) that the objective of using 2 data was the observed values of the second variable may help to improve estimates (predictions) of the first variable. Then the experiment of data set and its combination produced 3 types of point map set as follows:

- Cartosat-1 point map,
- Cartosat-1 point map + GPS points (merged into 1 variable before interpolation process)
- Cartosat-1 point map and GPS points (as 2 variables for Cokriging only).

The sets of point map used for DEM interpolation using different methods can be seen on Table 1.

3 RESULT AND DISCUSSION

The Data Preparation step (Figure 2) produced 3 types of point maps i.e. Cartosat-1 point map contained 45,763 point heights, GPS points contained 629 point heights, and Cartosat-1 point map + GPS points contained 46,392 point heights. Point map contained horizontal coordinate (X,Y) and height information (Z). Cartosat-1 point map is presented in Figure 3.

Twenty (20) DEMs were created in this research i.e., 8 DEMs derived from Cartosat-1 point map, 8 DEMs derived from Cartosat-1 point map + GPS points, and 4 DEMs derived from Cartosat-1 point map and GPS points (2 variables).

Table 1. Methods of DEM Interpolation

Method	Cartosat-1 point map	Cartosat-1 point map + GPS points	Cartosat-1 point map & GPS points
IDW	IDW	IDW2	-
GP	GP	GP2	-
LP	LP	LP2	-
RBF	RBF	RBF2	-
OK	OK	OK2	-
SK	SK	SK2	-
UK	UK	UK2	-
DK	DK	DK2	-
OCoK	-	-	OCoK
SCoK	-	-	SCoK
UCoK	-	-	UCoK
DCoK	-	-	DCoK

Where,

IDW : inverse distance weighted	OK : ordinary kriging	OCoK : ordinary cokriging
GP : global polynomial	SK : simple kriging	SCoK : simple cokriging
LP : local polynomial	UK : universal kriging	UCoK : universal cokriging
RBF : radial basis functions	DK : disjunctive kriging	DCoK : disjunctive Cokriging

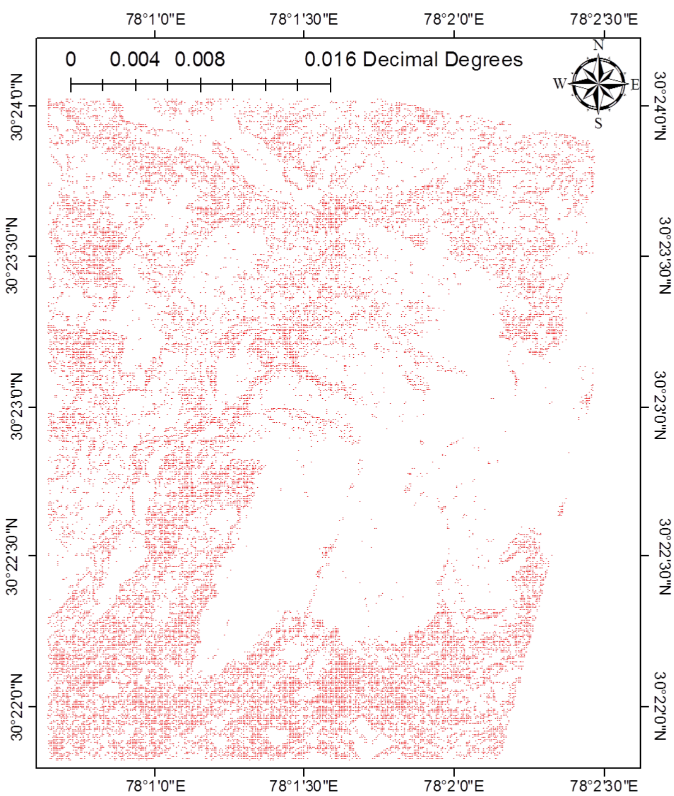


Figure 3. Cartosat-1 Point Map

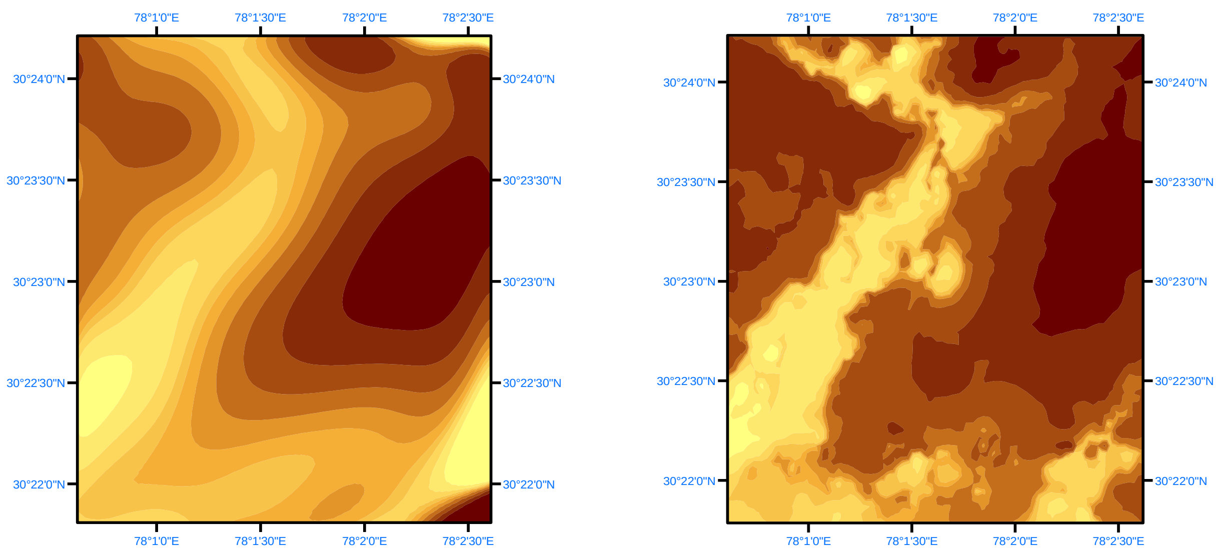
The contour based of DEM on the global polynomial interpolation is presented in Figure 4a. It had smoother contour but it did not represent the actual field condition compared to the contour based of DEM on ordinary kriging interpolation in Figure 4b. The ordinary kriging contour had coarser contour and more represent the actual field condition. The accuracy assessment is presented in Table 2 and in Figure 5. The analysis used the accurate GPS points observed on ground, accuracy assessment was done by measuring the height differences between generated DEMs and accurate GPS points. The detail accuracy for each point map is shown in Table 2.

The range of average error of DEMs was between 1.29 m to 2.96 m. Interpolation method that generate DEM with least average error was ordinary kriging that used the data of point map + GPS points, and the highest average error was global polynomial method that used the same data. Figure 6 shows the increasing average error due to method of interpolation. The result showed that ordinary kriging was the best interpolator which was also proven by previous research. The ordinary kriging had the least error compare to IDW, global polynomial, and local polynomial (Moradi *et al.*, 2012). Normal kriging method results in less error in comparison to other interpolation methods such as inverted weighted distance and Spline methods (Nezami and Alipour, 2012).

There was additional matter in discussion whether GPS points help much to increase the accuracy of generated DEM. As seen from Table 3 that the error of DEM could be reduced slightly using IDW, local polynomial, RBF, and kriging methods, while global polynomial method could not reduce the error by applying GPS points.

The GPS points as additional data to the point map did not affect in decreasing the error significantly. The average error on point map + GPs points is only 0.06 m better than point map data only.

Additionally, the image orthorecti-fication process was conducted using the DEM derived from interpolation results. The three dimensional (3D) visualization was then constructed to make easier in displaying the smooth or coarse the topographic surface. One sample of the visualization derived from ordinary kriging 2 DEM is shown in Figure 7.



a. Global Polynomial

b. Ordinary Kriging (2)

Figure 4. 2D Contour based of DEM on 2 Interpolators (Global Polynomial and Ordinary Kriging (2).

Table 2. DEMs errors (m)

Cartosat-1 Point map

Point	IDW	GP	LP	RBF	OK	SK	UK	DK
1	1.11	24.72	2.49	1.05	0.99	0.88	2.95	0.88
2	0.88	-17.76	0.92	0.95	0.95	1.08	0.97	1.08
3	2.74	-6.26	3.17	3.03	3.04	3.59	3.71	3.59
4	0.52	-12.14	0.95	1.18	0.32	0.46	0.23	0.46
avg. error	1.31	2.86	1.88	1.55	1.33	1.50	1.97	1.50

Cartosat-1 Point map + GPS Points

Point	IDW2	GP2	LP2	RBF2	OK2	SK2	UK2	DK2
1	0.84	24.10	1.61	0.89	1.01	0.89	2.95	0.89
2	0.88	-17.73	0.92	0.94	0.87	0.98	1.01	0.98
3	2.75	-6.22	2.84	3.01	3.03	3.57	3.73	3.57
4	0.73	-11.98	1.14	0.74	0.26	0.40	0.13	0.40
avg. error	1.30	2.96	1.63	1.40	1.29	1.46	1.95	1.46

Cokriging of Cartosat-1 Point map and GPS Points

Point	OCoK	SCoK	UCoK	DCoK
1	2.99	3.78	3.00	3.78
2	0.98	-0.07	0.97	-0.08
3	3.62	3.76	3.11	3.11
4	-0.75	0.18	-1.29	-1.28
avg. error	1.71	1.91	1.45	1.38

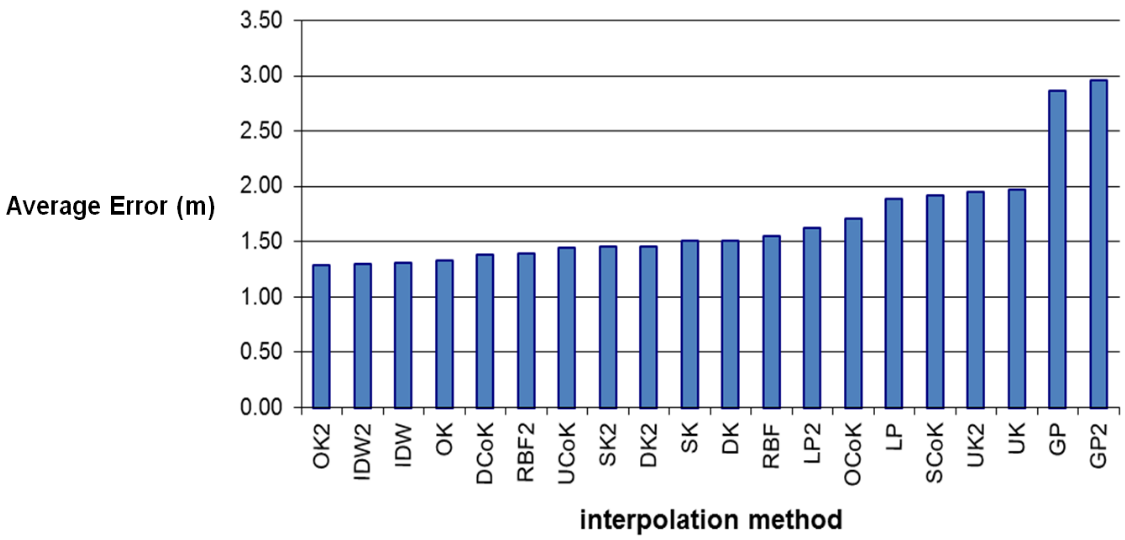


Figure 5. Cartosat-1 DEMs average errors in Ascending Mode

Table 3. DEMs average error based on data used

Int. Method	1 variable (m)		2 variables (m) Cokriging (point map & GPS)
	point map only	point map + GPS	
IDW	1.31	1.30	
GP	2.86	2.96	
LP	1.88	1.63	
RBF	1.55	1.40	
OK	1.33	1.29	1.71
SK	1.50	1.46	1.91
UK	1.97	1.95	1.45
DK	1.50	1.46	1.38
avg	1.74 / 1.57*	1.68 / 1.54*	1.61

* *for kriging method only*

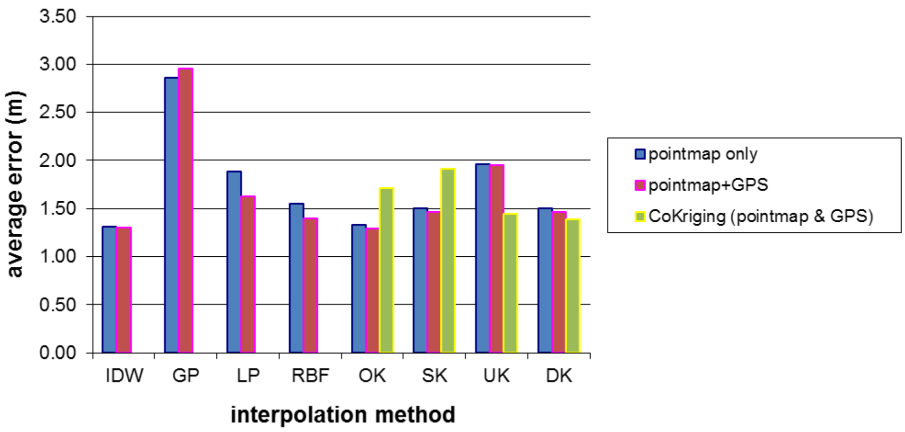


Figure 6. DEMs error based on data used.

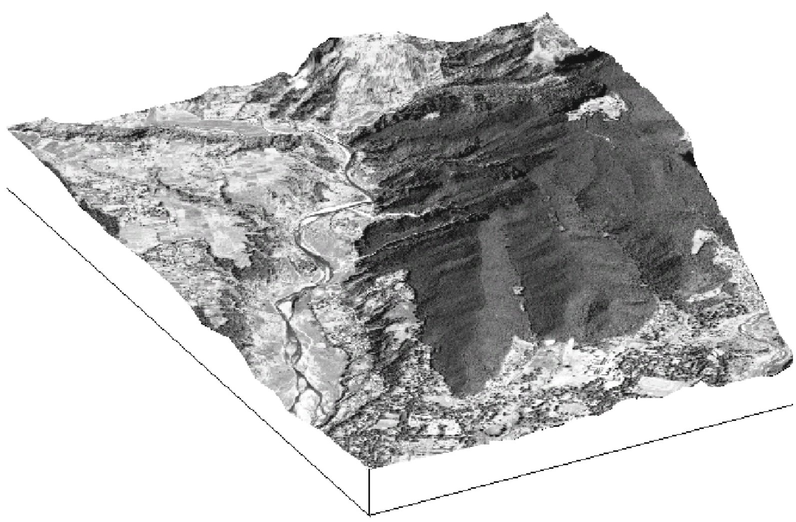


Figure 7. 3D visualization of DEM generated by ordinary Kriging 2 interpolator.

In this research, there was parameter which affected stereo processing. The process of defining conjugate points between two stereo pair images require good matching method, but from the lack of contrast of object in each image the points of height was difficult to generate. For example in forest area, there is no sharp object can be found compared to the settlement area.

4 CONCLUSION

Based on the analysis, the range error of DEMs generated was between 1.29 m to 2.96 m. Interpolation method with the least error was ordinary kriging using point map data and GPS points, while the highest error was obtained from global polynomial method. This study concluded that the best interpolation method for Cartosat-1 point map data was ordinary kriging with GPS points as additional data.

Although this research was conducted to study general aspects, it showed that interpolation technique could not easily result better outputs since it depends on data type, parameters, and method of interpolation. It was suggested to explore geostatistical aspects such as creating better parameters for each interpolator using one data type. It was also suggested to study variogram for better interpolated spatial data using kriging method.

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