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Extraction and accuracy assessment of DTMs derived from remotely sensed and field surveying approaches in GIS framework

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Abstract. Generating a high precision continuous surface is a key capability required in most geographic information system (GIS) applications. In fact the most commonly used surface type is a digital elevation model (DEM). Recently, there are some sources of remote sensing data that provide DEM information such as; LiDAR, InSAR and ASTER GDEM which ranged from very high to low spatial resolution. However, new methods of topographic field surveying still highly on demand e.g. Differential GPS and Total station devices. In both method of capturing the terrain elevation the post processing need to be applied to create a continuous surface from point clouds. Geostatistical analysis were used to interpolate the taken sample points from site into continuous surface. In current research, we examined the height accuracy of LiDAR point clouds and total station dataset with three non-adoptive interpolation models including, invers distance weightage (IDW), nearest neighbour (NN) and radial basis function (RBF) based on referenced DGPS points. RMSE and R square regression analysis were conducted to reveal the most accurate approaches in pilot study area. The results showed Lidar surveying (less than 0.5 meter RMSE) has higher height accuracy compared to Total station surveying (above 1 meter in RMSE) to extract DTM in flat area; while consumed less computational processing time. Moreover, IDW was the best and accurate interpolation model in both datasets to generate raster cautious terrain model.

1. Introduction

Remote sensing methods have been efficiently utilized in various fields for decision making due to their display capabilities and spatial analysis. The efficacy of analysis procedures is indeed meaningfully enhanced by using 3D geospatial models since they simplify interpretation and visualization. Digital Elevation Model (DEM) is the adopted data structure to store topographical information and is usually needed to be interpolated to create the height values for entire terrain areas[1]. DEM is a arithmetical demonstration of topography, typically create up of same-sized cells that indicate the value of elevation [2]. Generally, DEM might be derived from field surveys, topographic contour lines, radar interferometry, photogrammetry methods and laser scanning [3]. Since, topography is an important parameter that can controls the behave of natural systems, DEM is greatly valuable to cope with environmental phenomena [4]. Numerous Geographic Information Systems (GIS) applications are relying on DEM; for instance, hydrologic modelling [5], urban assessment studies [6, 7] soil distribution and erosion analysis [8]. There are some factors which effect on the quality of DEM negatively. Some of the existing surveying approaches can be classified

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into ground-based and airborne laser scanner which is suitable for moderately small terrain with very high resolution result [9]; while traditional topographic contour maps, high-resolution satellite images and common stereoscopic air-photos are being used for large areas surveying [10]. Light detection and ranging (LIDAR) knowledge is an active remote sensing surveying which has a great capability of concurrently mapping the terrain and surface of lands with sub-metre height vertical accuracy. The airborne LiDAR normally engages a laser scanner pulses to an inertial measurement unit (IMU) with global positioning system (GPS) for exact surveying [2]. Earlier investigation has revealed that the accuracy of DEM differs in different terrain and land use/land cover types [11]. Basically, LiDAR surveying errors can be into four modules included, surveying error, LiDAR system measurements uncertainty, interpolation errors and horizontal displacement malfunction [2]. This study experiments on interpolation errors and their techniques. As, LiDAR point clouds are not correspondingly distributed, the interpolation technique should be used to create unidentified points by using the magnitude and location of the known points [12]. Many interpolation methods have been implemented on geospatial application including, kriging, Spline, IDW and so one. Though LiDAR and Total station surveyed points has been broadly used in GIS frameworks, still a few researches were certainly discovered which interpolation methods is precise on discrete surveyed points with respect to mixed, hilly and flat trains [13]. Hence, in this research Lidar surveying using different non-adaptive interpolation methods were compared with field station surveying based on referenced definitional global positioning system (DGPS).The experiments were implemented on flat terrain where methods compared together in terms of height accuracy and computational time.

2. Materials and Methods

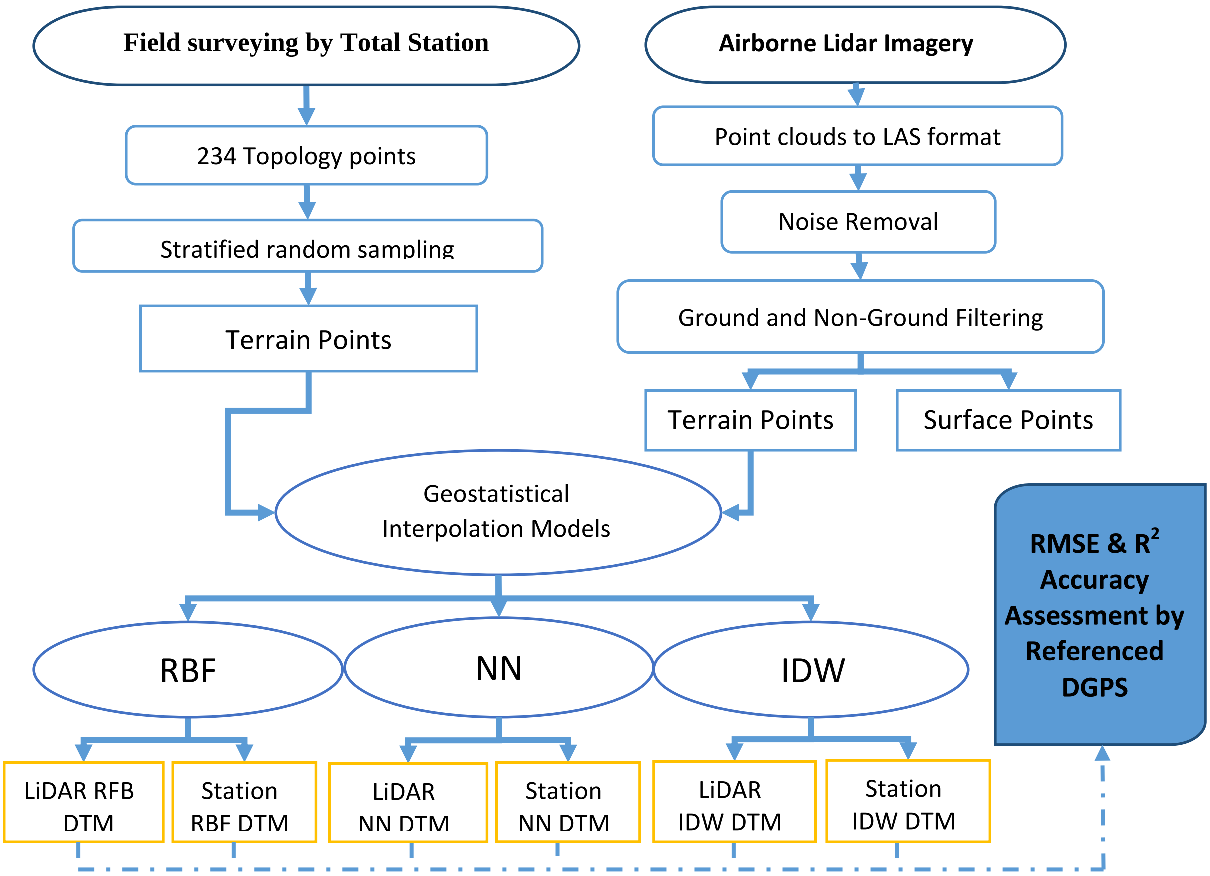

Figure 1. Computational flowchart applied in this study area

2.1. Study Area

The study area is a part of University Putra Malaysia (UPM) which covers an area of 4.34 hectare. It located at Selangor state of Malaysia where has longitude of 101° 42’ 55’’ to 101° 43’ 09’’ E and latitude 2° 59’ 17’’ to 2° 59’ 24’’ N. The study area is basically covered by mixed land cover including; railways, pasture, bare land and trees.

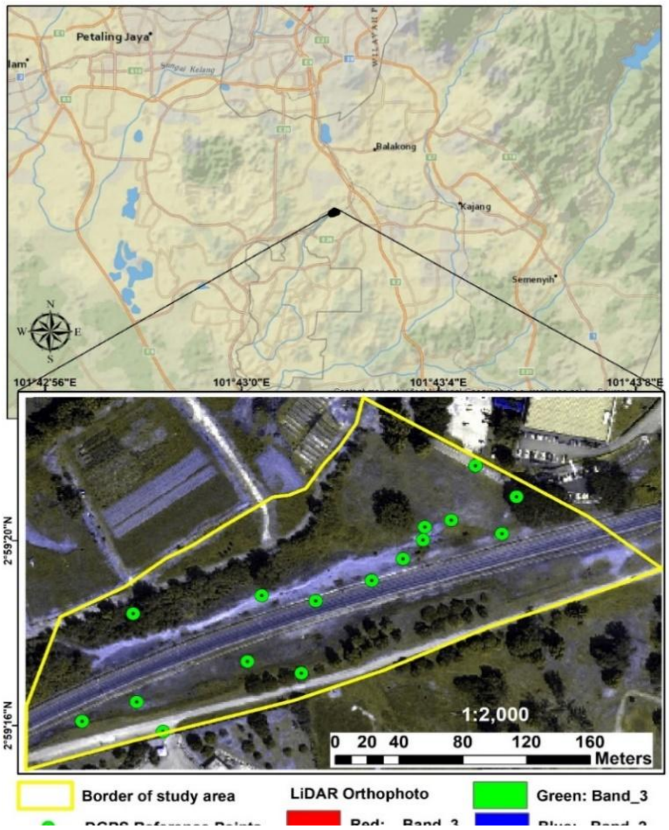

Figure 2. Location of the study area

2.2. Materials

2.2.1. Remotely sensed dataset. LiDAR point clouds were surveyed on 2015 using an airborne laser terrain mapper 3100 instrument in 1510 meter flying height. The density of points are almost 8 points per square meter with a 25,000Hz pulse rate frequency. The data accuracy or spatial resolution is 0.5 meter, regarding to point spacing. LiDAR data was collected in four different pulse returns (Table 1).

Table 1. LiDAR point clouds characteristics

Category	**Points count**	**Percentage**	**Height Minimum (meter)**	**Height Maximum (meter)**
First Returns	197904	94.71	44.79	667.62
Second Returns	9951	4.76	45.44	79.05
Third Returns	1042	0.50	45.54	77.47
Fourth Returns	55	0.03	46.92	67.90
All Returns	208952	100.00	44.79	667.62

2.2.2. Field practical survey. Field surveying was conducted by using Total station TOPCPN GTS-230N Series. GTS-230N Series have their basic functions for distance and angle measurement in addition to maintaining superb durability against the environment. Basically, a total station device combines a digital theodolite and an Electronic Distance Measure (EDM) that work together with a microprocessor to rapidly and accurately perform tasks.

2.2.3. Reference dataset. Sixteen height DGPS points were collected from study area. They cover the entire study area and was collected following a stratified random sampling strategy. DGPS provides differential corrections to a GPS receiver in order to improve navigation accuracy and monitors the integrity of GPS satellite transmissions. The CHC X91 GNSS Receiver was used to take DGPS sampling points with less than 2 cm accuracy which uses 220 Channel, Enhanced GNSS technology supports L2C, L5, SBAS, GLONASS and Galileo, Advanced Multipath Mitigation and Low Noise Carrier Phase Measurement.

2.3. Methods

Three geostatistical interpolation method namely invers distance weightage (IDW), radial based function (RBF) and nearest neighbour [4] were performed on both LiDAR and field station surveying points to create elevation model. Derived DTMs were evaluated with the DGPS reference points to given study area. Adopted methodology is illustrated in Figure 2. In this study, 252 ground Points were collected by total station surveying within 18 hours at every changes of ground surfaces and/or every 10m depending on the surface of the ground. The more points per area or densely collected points will result in a much better accuracy.

2.3.1. LiDAR Pre-processing. Clouds points should be first converted to LAS format and then filtered into first return and ground return to separate surface from train model, respectively [14]. Next step is Lidar Noise removal which is detect and remove likely noise points from loaded or selected Lidar data. Unclassified Point Clouds were selected to Find Likely Noise Points In. Then, apply Maximum Allowed Variance from Local Average in order to highlight Outside Elevation Range (noise) and eliminate them [11]. All the pre-processing steps were done in Global mapper v.19 in WGS-84 datum. After filtering and noise removal, point clouds were sampled into a regular grid, and ready for next step which is interpolation.

2.3.2. Interpolation methods

a) Inverse Distance Weighting concept. The IDW mathematical concept is assumed things that are nearby to another are more similar rather those that are farther apart and obtain higher weightage [15]. To calculate a value for unexampled area, IDW uses the inverse measured values surrounding the prediction place.

$$\boldsymbol{z_p} = \frac{\sum_{i=1}^{n}(\frac{\boldsymbol{z_i}}{\boldsymbol{d_i}})}{\sum_{i=1}^{n}(\frac{\boldsymbol{1}}{\boldsymbol{d_i}})} \qquad (1)$$

where, z_p is estimation value of variable z in point I; z_i stands as sample value in point I; d_i is distance of sample point to estimated point and n shows the total number of predictions.

b) Radial Basis Functions concept. The RBFs are equivalent to fitting out a rubber membrane by the observed sample values, while reducing the sum of the curvature of the surface [16]. The selected basis function specifies, how the rubber membrane will match between the measures. Radial basis functions are typically used to build up function approximations of the form:

$$\boldsymbol{y}(\boldsymbol{x}) = \sum_{i=1}^{n} \boldsymbol{w_i}\, \emptyset(\|\boldsymbol{x} - \boldsymbol{x_i}\|) \qquad (2)$$

Here y(x) is the sum of the number of radial basis functions, where each item related to distinct centre xi and weighted by suitable factor of w_i.

c) Nearest Neighbour Interpolation concept. The NN interpolation was developed by Sibson [17], which use Voronoi & Delaunay graph which is a discrete diagram of spatial points. For interpolation, it exert weight on the nearest points based on their proportional areas. Relevant equation which is used for NN interpolation method is:

$$\boldsymbol{G}(\boldsymbol{x}, \boldsymbol{y}) = \sum_{i=1}^{n} \boldsymbol{w_i}\, \boldsymbol{f}(\boldsymbol{x_i}, \boldsymbol{y_i}) \qquad (3)$$

where: G(x, y): *Evaluated* value of nearest neighbour in (x, y);N: Number of nearest neighbours used at interpolation; $f(x_i, y_i)$ Shows observed values at (x_i, y_i) and w_i: *A*ssociated weight. The weights are estimated while deciding what portion of neighbouring area needs to be taken when creating diagrams [13].

2.3.3. Accuracy Assessment. Statistical parameters and visual analysis have been used for comparative assessment of the interpolated areas. During visual analysis via field visiting, DEM generated elevations were controlled via GPS and observational methods. Statistical analysis has been accomplished by measuring the standard deviations of interpolated elevation values from commensurate observed values according RMSE (Root Mean Square Error)[18]. The RMSE is defined as the square root of the mean squared error:

$$\mathbf{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(X_{ref,i} - X_{int,i})^2}{n}} \qquad (4)$$

where $X_{ref,i}$ is referenced values and $X_{int,i}$ is interpolated values at time/place i.

3. Results and discussions

3.1. Surveyed DGPS Data for Elevations bench mark

Basically, 50 GNSS reference stations are located in Peninsular Malaysia though which surveyed DGPS points can be corrected either real time or post processed one. They computes the correction for their positions based on geodetic network measurements and atomic horologe [19]. Accordingly, in this study, the used DGPS were corrected by post processing approach. Sixteen DGPS ground truth points were selected based on the topographic variability between receivers without any obstruction with accuracies of ± 1 cm to ± 2 cm. These points were uniformly distributed over the study area. The amount of GDOP (geometric dilution of precision) and PDOP (position dilution of precision) uncertainties, which describes error caused by the relative position of the GPS satellites, are very low among all collected DGPS points. Also, recorder heights were measured based on both mean see levels (MSL) or Geoid and Ellipsoid which are projected in UTM WGS19984 coordinate system.

3.2. Comparative analysis of interpolation methods

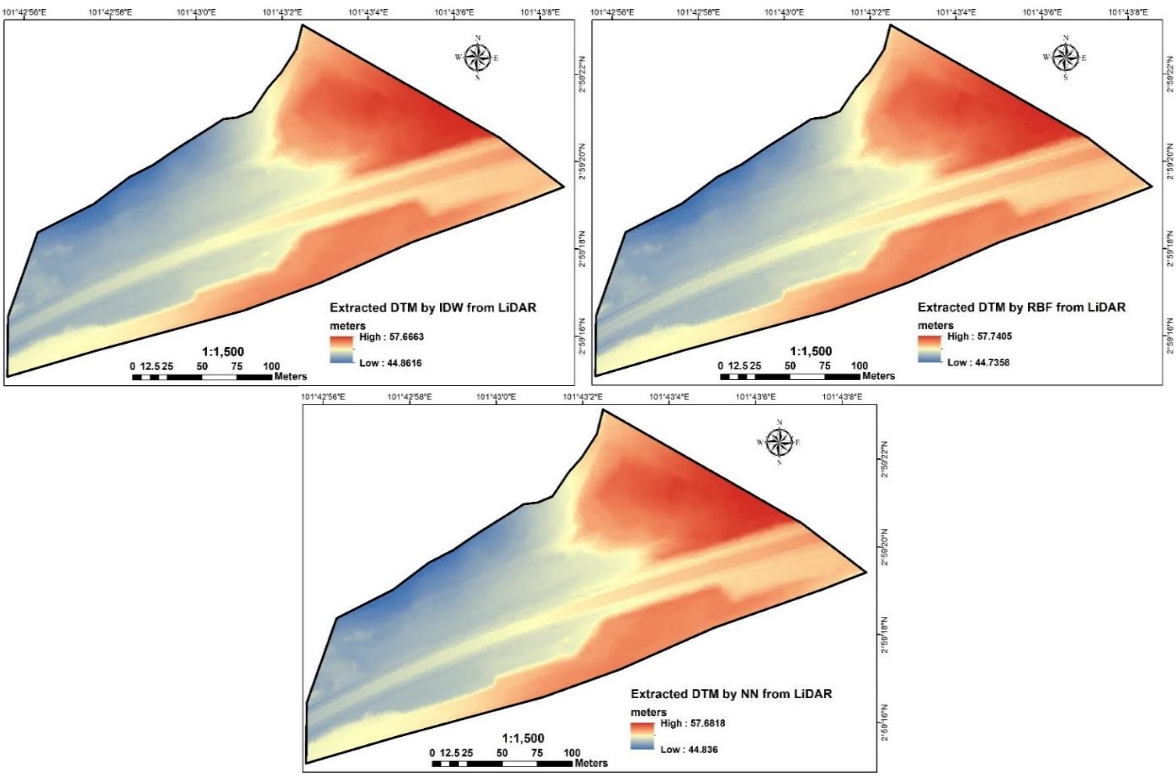

Figure 3. Visual presentation on derived DTM from LiDAR dataset

Elevation points from Lidar and Total station were investigated regarding to different interpolation methods with reference to numerous terrain circumstances. Visual comparisons as well as mathematical accuracy analyses have been conducted.

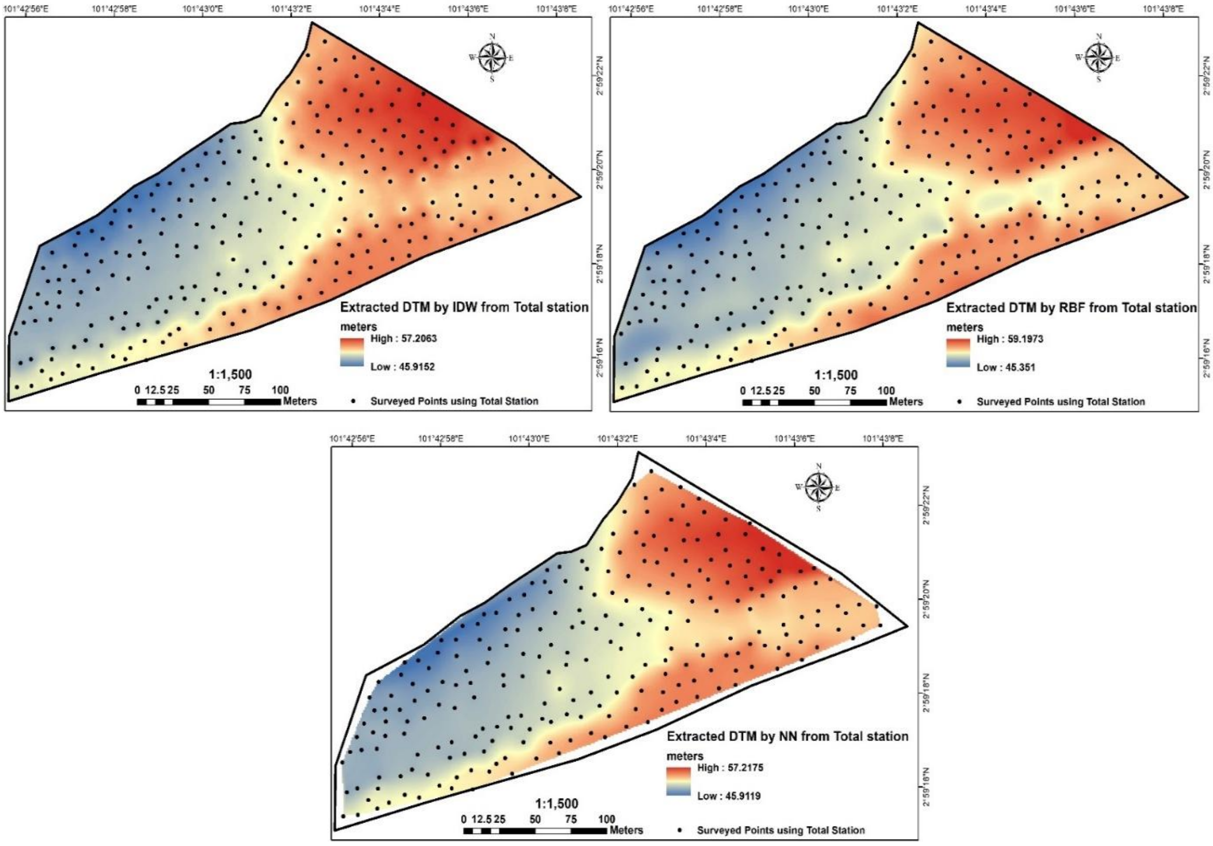

Figure 4. Visual presentation on derived DTM from Total Station field surveying

Visual comparison of elevation models generated using different interpolation techniques is presented in Fig. 2. As, LIDAR data has holes so, non-adaptive IDW, RBF and NN interpolation are applied to automatically identify and fill the gaps to acquire a higher and smooth resolution grid surface. In LiDAR visual presentation there was no significant differences in terms of pattern and features between the terrain elevations among different interpolation methods (Fig. 3); however, the elevation maximum and minimum range were fluctuated from one to another model. For example in RBF model the maximal was 57.7405 meter and low altitude was 44.7358 meter which showed the highest and lowest interpolated elevation n compared with IDW and NN. Basically, extracted terrain characteristics by Total station surveying with 252 points are not as precise as 208952 Lidar point clouds. However, DTMs which derived by IDW and RBF methods are more similar to LiDAR pattern terrain (Fig. 4).

DGPS Ellipsoid elevation value is much closer to measure height rather MSL for height assessment (Table 2). In order to discover the most accurate interpolation models, we need to apply detailed statistics tests including R square regression and RMSE. DTMs were compared to ground truth DGPs in different location randomly.

Table 2. Compared extracted DTMs with DGPS Reference points

No	Referenced DGPS Height points (meter)		Extracted DTM from LiDAR (meter)			Extracted DTM from Total Station (meter)		
	MSL	Ellipsoid	IDW	RBF	NN	IDW	RBF	NN
1	59.352	57.385	57.078	56.870	56.867	56.283	56.002	55.985
2	59.655	57.690	57.377	57.178	57.182	56.574	56.262	57.146
3	59.126	57.161	56.975	56.895	56.807	54.421	54.680	54.312
4	57.960	55.994	55.732	55.517	55.506	55.029	54.733	55.628
5	57.448	55.482	55.202	55.013	55.007	54.179	53.989	54.072
6	55.898	53.931	53.897	53.730	53.691	53.227	53.122	53.116
7	54.320	52.353	52.071	51.851	51.851	51.550	51.086	51.982
8	54.194	52.227	52.749	51.456	51.467	51.568	50.528	50.480
9	53.085	51.117	51.211	51.092	51.049	50.198	50.093	50.798
10	52.340	50.370	49.981	49.769	49.778	49.375	49.125	48.968
11	50.158	48.187	47.982	47.809	47.800	46.700	46.623	47.397
12	52.736	50.767	50.509	50.300	50.300	49.845	49.543	48.741
13	56.431	54.464	54.121	53.920	53.927	52.534	52.809	52.446
14	54.636	52.667	52.286	52.099	52.083	51.294	51.174	50.977
15	51.553	49.583	49.227	48.999	49.018	49.204	48.244	49.404
16	51.327	49.355	49.107	48.908	48.929	49.145	48.795	49.112

The standard deviation, average, minimum and maximum height values were extracted and mathematically can prove which model has received the lowest error and uncertainties (Table 3).

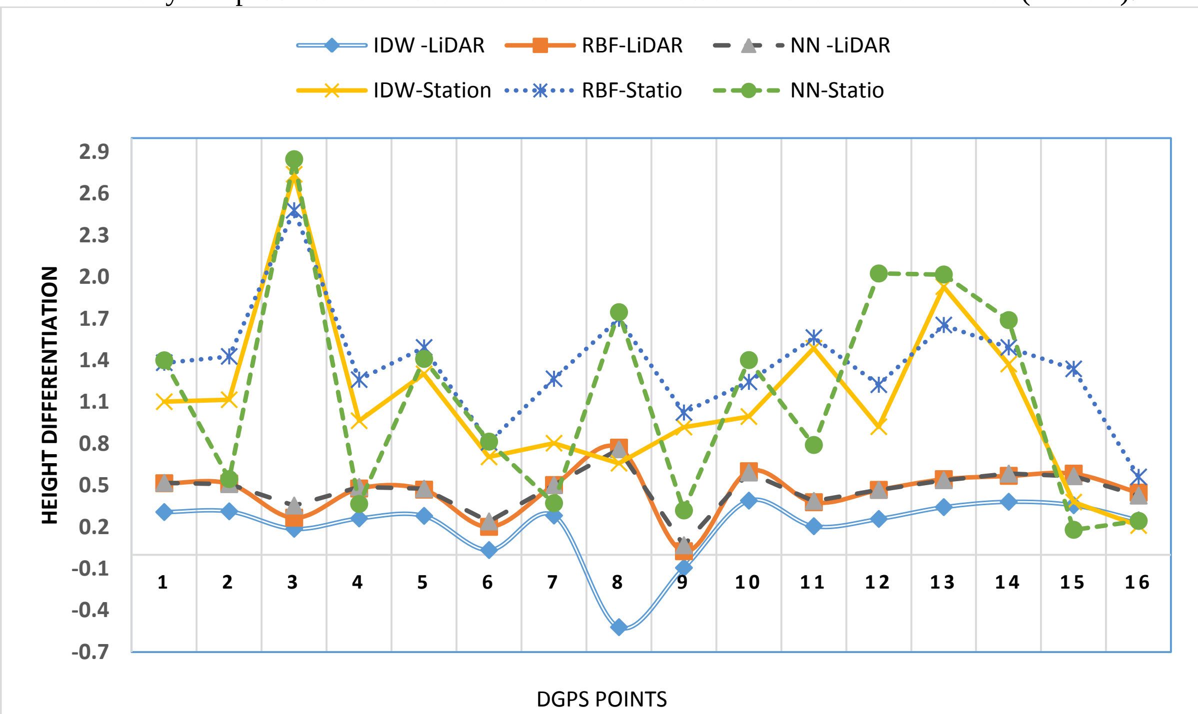

Figure 5. Height differentiation between interpolated models and referenced DGPS points.

The LiDAR-derived DTM as well as total station-derived DTM for the entire study under-predicted the ground elevation when validated with the DGPS ground truth data, with an average overall mean error of 0.4 and 2.01 meter, respectively (Table 3). LiDAR cloud points are more constant and accurate than Total station surveyed points (Fig. 5). Some techniques have been suggested for DEM quality assessment to achieve its accuracy and precision. Precision is typically assessed by equations without spatial dimension e.g. the mean absolute error (MAE) or the root mean square error (RMSE) and R square regression method.

Table 3. Accuracy assessment and statistical test results

Test	IDW -LiDAR	RBF-LiDAR	NN -LiDAR	IDW-Station	RBF-Station	NN-Station
Standard deviation	3.056	3.079	3.068	2.835	2.920	2.914
RMSE	0.301	0.488	0.491	1.247	1.329	1.473
R-square	0.997	0.996	0.994	0.980	0.960	0.922

It is shown that Total station surveying is low accurate (above 1 meter in RMSE) than Lidar surveying (less than 0.5 meter RMSE) to extract DTM in flat area while consumed more time. In fact, it took several hours to complete rather than several minute for Lidar mapping. Table 3 shows that IDW showed more precise result (0.301 and 0.997 RSME and R^2) which followed by RBF and NN. Additionally, the same ranking of interpolation models were observed in Total station where IDW performed with highest accuracy (1.25 meter in RMSE and 0.980 R^2) to interpolate DTM with respect to referenced DGPS truth points.

4. Conclusion

Current study examined two different high quality dataset that have been collected by remotely and on filed approaches namely, LiDAR point clouds and Total station surveying over a flat terrain. We also investigated the comparison experiments on various geostatistical interpolators such as IDW, RBF and NN. Extremely accurate DGPS was used as bench mark to compare methods and datasets. The results showed even though both collected data are very reliable, LiDAR dataset is not only more accurate but also is a fast surveying method to collect height information. Moreover, IDW was the best and accurate interpolation model in both datasets to generate DTM due to its mathematical concept and distribution of samples on study area.

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