Effectiveness of Interpolation Methods for LiDAR Point Cloud Intensity Imaging

Imran Ashraf[1], Soojung Hur[1] and Yongwan Park[1]

Abstract— **Light Detection and Ranging (LIDAR) has become the most widely used tech-nology for intelligent vehicles in the recent past. LIDAR system captures data not only in normal conditions, but also during rain and snow with increased accu-racy and precision. Intensity images generated from reflecting of laser beams are fur-ther used for feature analysis, distinct object analysis and data fusion. Interpola-tion techniques are used for two purposes: to generate unknown points where cloud point is very thin or no points at all and adding more data to cloud point to get more detailed intensity image. Henceforth, LIDAR data density and interpola-tion methods are of chief interests to produce intensity images. This paper inves-tigates interpolation methods including Natural Neighbor, Trilinear and Nearest Neighbor for their effectiveness to generate the intensity image. Correlation anal-ysis and Root Mean Squared Error (RMSE) show that Natural Neighbor achieves highest correlation of 0.9420 with actual intensity image and has lowest RMSE.**

I. INTRODUCTION

Light detection and ranging (LiDAR) has become intensively used technology for intelligent vehicles in the recent decade. Besides providing data for normal weather, the less limitation of weather like rain and snow and time of day makes it more suit-able to capture 3D surface information than other sensors [1]. Owing to LiDAR data capture speed and precision, it has become established tool for many areas of intelli-gent vehicles like road detection [2], curb detection, obstacle detection [3], etc.

Recent advanced high definition LIDAR technology like Velodyne HDL-64E is able to provide exponentially more data intensive point cloud (66k$\sim$266k per revolu-tion/1.3 million points per second) than traditional rotating mirror LIDAR [4]. How-ever, it is computationally expensive to process huge cloud of points especially when we have to perform LIDAR data fusion with other sensors like RADAR and color camera etc. Intensity based data fusion is one of the commonly used image registra-tion methods and is widely researched area [5]. In literature many research works can be found who used LIDAR intensity images for fusion with other sensors. Zhang et al. [6] used intensity information with aerial images to eliminate coordinate errors in LIDAR data using LIDAR Strip Adjustment (LSA). Triangulated Irregular Network (TIN) and intensity images are built using LIDAR data then conjugate points between these images are matched and served as control points for LSA.

LiDAR data is very important, yet processing large cloud point is computationally complex and time consuming. Instead a sparse cloud point is taken and interpolation techniques can be used to generate intensity images. The objective of this study is to investigate the relationship between raw LiDAR data, decimation and various interpolation techniques.

*This work was supported by This research was supported by the Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(RS-2021-NR060120)

[1] Imran Ashraf, Soojung Hur, and Yongwan Park are with the School of Computer Science and Engineering, Yeungnam University, Republic of Korea. imranashraf@yu.ac.kr; sjheo@ynu.ac.kr; ywpark@yu.ac.kr

II. METHODOLOGY

This study investigates the feasibility of using the interpolation techniques for missing LiDAR data to reduce computational complexity. In addition, missing data as a result of bad weather such as rain, fog, or snow can also be generated. Figure 1 shows the workflow of the used methodology.

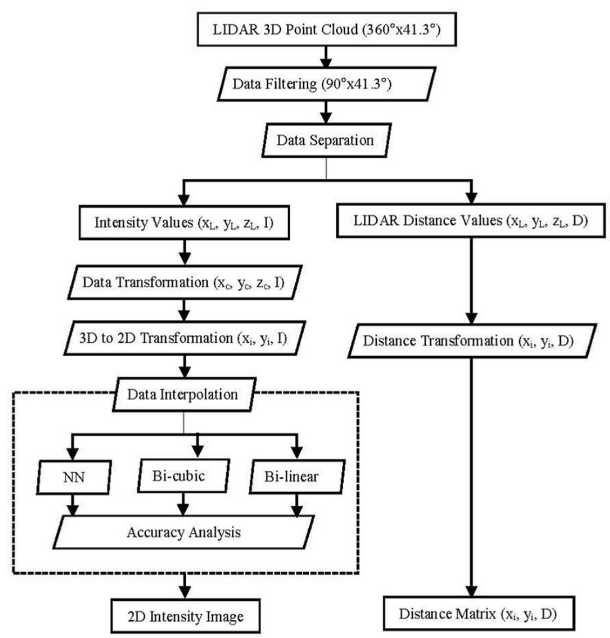

Fig. 1. Workflow of the adopted methodology.

Interpolation is a statistical technique capable of potentially generating the unknown points between known points. It is used to produce intermediate unknown values of independent variable for spatial data Natural neighbor invented by Sibson is a well-known technique for spatial interpolation. Invented by Robin Sibson, it uses Voronoi and Delaunay diagrams of a discrete set of spatial points [4]. In order to interpolate a value, it applies weight to closest points based on their proportionate areas. General equation used for natural neighbor is

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

where $G(x,y)$ is the estimated value of natural neighbor at (x,y), and n is the number of nearest neighbors.

Linear interpolation (also called curve fitting) is a numerical analysis technique which uses linear polynomials to derive a straight line between the given known points.

$$y = y_0 + (y_1 - y_0)\frac{x - x_0}{x_1 - x_0} \tag{2}$$

Since, LiDAR intensity images has 3D data so trilinear interpolation is used for the experiment.

Nearest neighbor method is widely used in many areas like image processing, ma-chine learning etc. and has very simple methodology. It approximates the value of a point in space given the points neighboring that point. Contrary to natural neighbor which selects neighboring points, nearest neighbor selects the nearest point. For our experiment four neighboring points are used to calculate known points.

Data is collected using Velodyne HDL-64E mounted on the vehicle in the urban area of Gyeongsan, South Korea during afternoon time and for normal weather conditions. Raw data is processed using Matlab R2015a. For experiment one frame is taken into account and one frame implies one 360° revolution of the LIDAR. To perform the experiment raw data is decimated at 10%, 25%, and 50% for point cloud. Next, three selected interpolation techniques are applied to generate intensity images. Finally, the generated intensity images are compared to find the correlation coefficients on point to point basis.

In order to check the accuracy of interpolated points correlation analysis is per-formed. In addition, Root Mean Squared Errors (RMSE) and Mean Absolute Deviation (MAD) is calculated to check how closely the interpolated data fit the actual data points. To calculate RMSE all intensity values of one frame are selected and calculations are performed based on the following equation

$$RMSE = \sqrt{\frac{\sum (I_{interp} - I_{ref})^2}{N}} \tag{3}$$

where I_{interp} shows the interpolated intensity point from one of the selected interpolation techniques, I_{ref} is the reference intensity point and N represents number of points for RMSE calculation.

III. RESULTS

For experiments involving data collection from autonomous vehicle, we used the vehicle shown in Figure 2. Velodyne HDL-64E is used for data collection and experiments involving data decimation and interpolation.

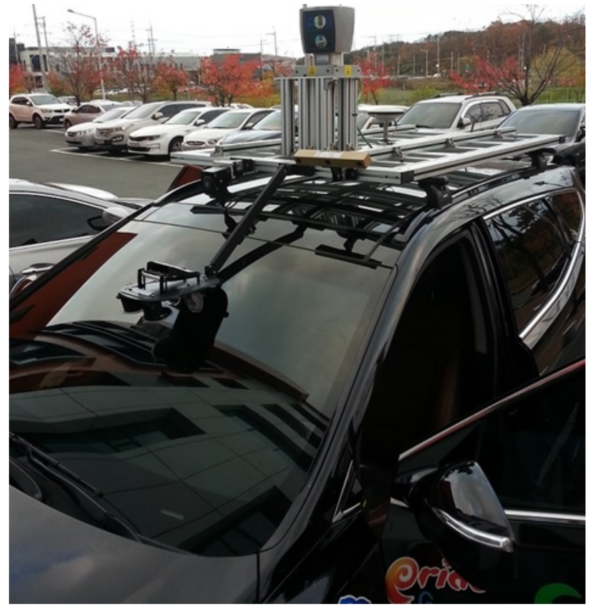

Fig. 2. Vehicle used for data collection.

Correlation coefficient measure is used in order to check the statistical correlation between the actual data points and interpolated data points. The value of correlated coefficients varies between -1 and +1. The sign indicates the direction of correlation while magnitude shows the goodness of fit of points.

TABLE I
CORRELATION COEFFICIENT BETWEEN GENERATED AND REFERENCE INTENSITY POINTS.

Technique	**50%**	**35%**	**25%**	**10%**
Nearest Neighbor	0.7575	0.8114	0.8733	0.9158
Trlinear	0.8149	0.8833	0.9055	0.9380
Natural Neighbor	0.8250	0.8899	0.9110	0.9421

Table I shows the calculated coefficients for selected interpolation techniques. The highest correlation is achieved when we perform Natural Neighbor interpolation on data at 10% decimation. It is also observed that Natural Neighbor achieves higher correlation for data at 10%, 25% and 35% decimation as well in comparison to other interpolation techniques.

Nearest Neighbor techniques improves the correlation coefficient as we increase the known points from 10% to 25%. Similarly, Linear Interpolation generates points more accurately when we increase the known points by reducing the missing data from 50% to 35% and then to 25%, respectively. According to the results of Table I, it can be stated that the interpolation techniques perform better when we increase known points to perform interpolation. Higher correlations are contributed with less decimated data.

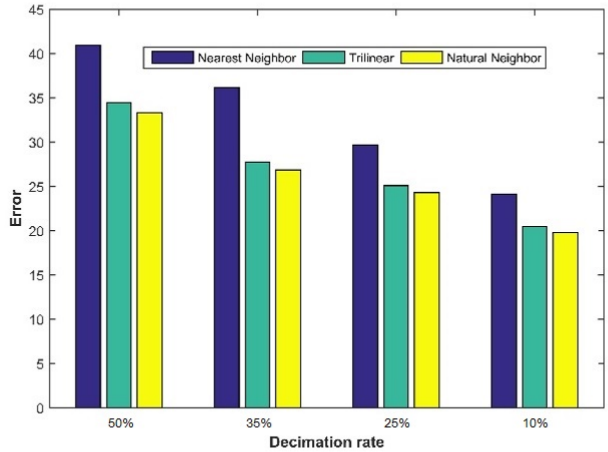

Fig. 3. RMSE error for intensity images

RMSE determines how close the interpolated points are from the reference points for specific given coordinates. It shows the accuracy of generated points at empty locations. Figure 3 shows the graph for calculated RMSE for three selected interpola-tion techniques. After examining the RMSE, it can be stated that decimation rates are directly affecting the accuracy of the interpolation.

Besides RMSE, Mean Average Deviation (MAD) is also calculated to check the deviation of interpolated intensity points from mean know values. MAD is calculated using

$$MAD = \frac{1}{N}\sum_{i=1}^{N}|I_i - \overline{I}| \tag{4}$$

where N represents the number of points, I_i is the interpolated point and $\overline{I}$ shows the mean intensity value.

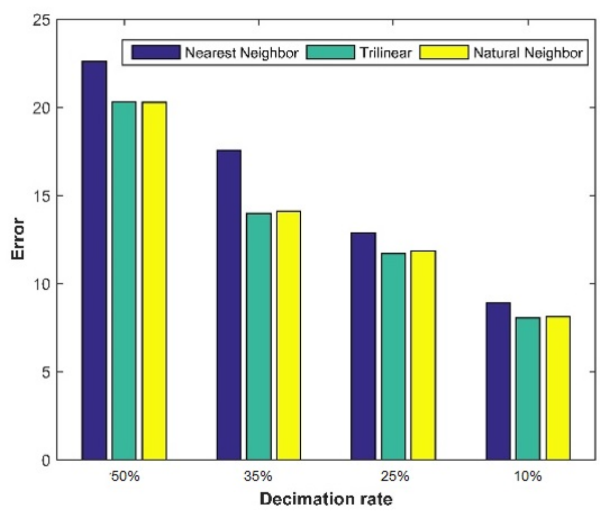

Fig. 4. RMSE error for intensity images

Results shown in Figure 4 are in conformation with RMSE results. Nonetheless, MAD values show the minimum error for Trilinear interpolation at 10% decimation rate. For MAD error Trilinear technique has lowest deviation rate for every decimation level. Though correlation results for Trilinear and Natural Neighbor are very close, yet Natural Neighbor has outperformed other interpolation techniques in every category of decimation. Results of experiment show that LIDAR intensity values can be used to successfully interpolate both unknown values at different locations.

Figure 5 is the reference intensity image used to compare the interpolated values for the selected interpolation techniques. Figure 6 shows the result of Natural Neighbor interpolation technique at 50% decimation rate. After examining the results it is clear that only small difference in the image is perceptible. Most of the false points are generated in the range of 70 to 120 intensity due to which generated image gives greener look than the actual image. However, these values are only 6% as 94% of the interpolated points are correlated with actual intensity points. Based on the accuracy and correlation results, it is possible to assume that Natural Neighbor interpolation technique can be used to create missing points in the cloud point and to generate additional points to add more detail to LIDAR intensity image.

IV. CONCLUSION

In this paper, raw LIDAR intensity data is processed using Matlab and decimation is performed at 10%, 25%, 35% and 50%. Three interpolation techniques including Nearest Neighbor, Trilinear and Natural Neighbor are applied to generate unknown intensity values at various coordinates. The suitability and accuracy of selected methods is evaluated by comparing interpolated intensity values with actual intensity points. Experiment shows that interpolation works quite satisfactory even at a low decimation rate. Though a large number of interpolation methods exist but it is very hard to exactly suggest which method is the best one. However, based on the experiment it can be assumed that Natural Neighbor is most suitable to interpolate intensity values. It has the lowest RMSE error of 19.7769. Besides, it has higher correlation coefficient of 0.9420 and its correlation coefficient is high for all decimations as compared to other selected techniques. Intensity images generated using interpolation can be used in intelligent vehicles for objects detection as well as for sensor fusion process.

REFERENCES

[1] G. Kim and Y. Park, "Lidar pulse coding for high resolution range imaging at improved refresh rate," *Optics Express*, vol. 24, no. 21, pp. 23810–23828, 2016.

[2] G. Kim *et al.*, "Coded pulse stream LiDAR based on optical orthogonal frequency-division multiple access," *IEEE Access*, vol. 11, pp. 142734–142747, 2023.

[3] G. Kim *et al.*, "A novel cycloidal scanning LiDAR sensor using risley prism and optical orthogonal frequency-division multiple access for aerial applications," *IEEE Access*, vol. 12, pp. 47724–47745, 2024.

[4] Velodyne LiDAR, *HDL-64E S2 User's Manual*, 2015. Accessed on 10 December 2025.

[5] E. G. Parmehr, C. S. Fraser, C. W. Zhang, and J. Leach, "Automatic registration of optical imagery with 3D LiDAR data using statistical similarity," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 88, pp. 28–40, 2014.

[6] Y. Zhang, X. Xiong, M. Zheng, and X. Huang, "LiDAR strip adjustment using multifeatures matched with aerial images," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 53, no. 2, pp. 976–987, 2015.

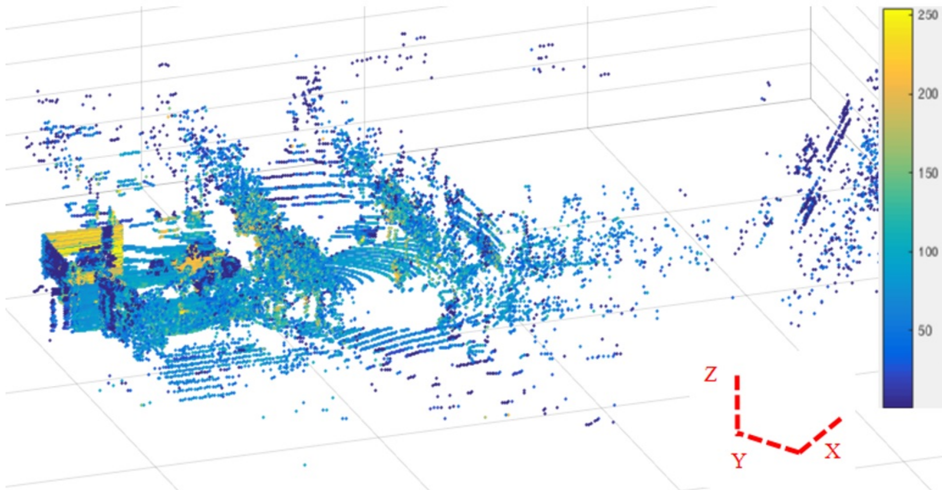

Fig. 5. Reference intensity image.

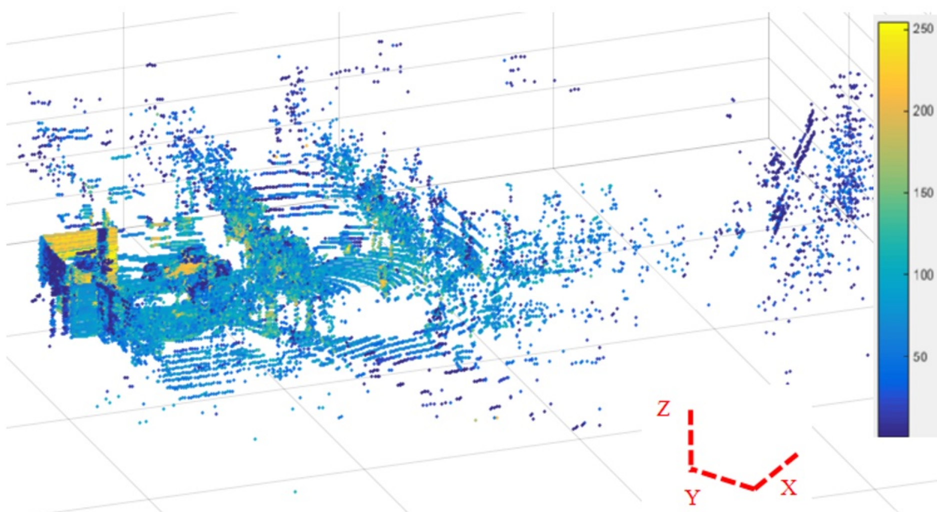

Fig. 6. Generated intensity image using Natural Neighbor technique.