# A Comparative Evaluation of Point Clouds Data Acquired Using Drone LiDAR in Various Terrains

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***Abstract*****:** *LiDAR technology collects precise 3D spatial information by integrating lasers with high-precision IMUs and GNSS. Advancements in sensor technology have enabled the use of LiDAR on drones for the efficient acquisition of high-resolution point cloud data. Specifically, LiDAR's multi-return signal processing technology records multiple reflections from a single laser pulse, allowing the sensor to penetrate obstacles like dense foliage and effectively acquire point data from the ground surface. In this study, data was acquired and performance was compared in a forested area, flat terrain using a DJI Matrice 350 RTK drone equipped with Zenmuse L1 and L2 scanners. The scanning altitude was varied from 50 to 150 meters. The study found that the L2 demonstrated higher point density and superior vertical (Z-axis) precision compared to the L1. Notably, it effectively acquired ground point cloud data even within complex, densely vegetated forest environments. Additionally, it was confirmed that while multi-return signals can be useful in complex terrains like forests, they may not always provide reliable point cloud data depending on the specific scanning environment. For simple flat terrain or sparsely forested areas, the study found that using only the first, second, and third returns is sufficient to acquire reliable data. In conclusion, the L2 strength in collecting reliable point cloud data and performing accurate 3D terrain modeling in complex terrain makes it a suitable instrument for disaster cause investigation and precision terrain analysis.*

*Keywords: Drone LiDAR, Point Cloud, Multiple return, Point density, Ground point*

## Introduction

In disaster situations, rapid and accurate investigation of causes is essential for minimizing damage and preventing recurrence. Advances in Unmanned Aerial Vehicle (UAV) technology have introduced significant innovations in this field. In particular, UAVs equipped with LiDAR sensors provide precise three-dimensional data on complex terrain and structural deformations, even in inaccessible disaster sites, thereby enhancing disaster response capabilities.

Several previous studies have examined UAV-based LiDAR applications. Diara (2022) analyzed the influence of environmental conditions and flight parameters on accuracy, focusing on point cloud quality and spatial positioning. Kersten et al. (2022) evaluated the accuracy and data quality of the Zenmuse L1 LiDAR and P1 camera sensors, comparing their performance with terrestrial laser scanning (TLS) data. Park et al. (2023) conducted an analysis of LiDAR characteristics, application methods, and equipment accuracy verification procedures to establish a validation plan for point cloud data accuracy acquired via drone LiDAR. Bartmiński et al. (2023) evaluated data quality issues occurring in complex terrain and dense forest areas, highlighting the operational limitations of the DJI Zenmuse L1 sensor.

However, in natural disasters—particularly in forested regions—dense tree canopies often hinder the acquisition of ground point clouds, limiting the effectiveness of L1 LiDAR sensors. To overcome this limitation, the recently developed L2 LiDAR sensor offers significant improvements. At a distance of 100 m, its laser spot size is 4 × 12 cm, five times smaller than that of the L1, which enables the collection of higher-density point cloud data. Furthermore, its five-return capability records up to five reflections from a single laser pulse, allowing accurate detection of ground surfaces beneath dense vegetation. This makes it possible to separate ground and non-ground points, thereby facilitating the generation of precise Digital Terrain Models (DTMs).

In this study, we conducted experiments to compare the ground point cloud acquisition performance of the L1 and L2 LiDAR sensors. The test site was a forested area in Ulju-gun, Ulsan, South Korea. The experiments were carried out using DJI's Matrice 350 RTK UAV equipped with both the Zenmuse L1 and L2 sensors, which are widely used in recent research.

## Research methods

The experiment was conducted in Sangbuk-myeon, Ulju-gun, Ulsan, South Korea. The study area comprised two types of terrain: gently sloped forest with dense vegetation (Area A), steeply sloped forest with dense vegetation (Area B).

The objective was to evaluate whether point cloud data penetrated to the ground and to compare the penetration performance of the L1 and L2 sensors. In Area A, LiDAR scanning was conducted at flight altitudes of 50 m, 80 m, 100 m, and 150 m. Aerial targets measuring 70 × 70 cm were installed beneath vegetation in gently sloped forest areas. The acquired point cloud data were then analyzed. In Area B, scanning was conducted at 50 m and 80 m over both steeply sloped forest with dense vegetation and flat terrain. Identical aerial targets were installed, and the Z-values of the acquired point clouds were compared with GNSS control point data to assess absolute accuracy.

Point clouds within a 1 cm radius of each target center were considered unaffected by micro-topographic variation, and their mean Z-values were used for analysis. In addition, point density and multi-return characteristics of the point clouds collected over the targets were evaluated.

Ground control points were surveyed using a Trimble R10 GNSS receiver. A total of 14 reference points were collected: 7 within the forest interior of Area A, 7 within the forest interior of Area B (Fig. 1).

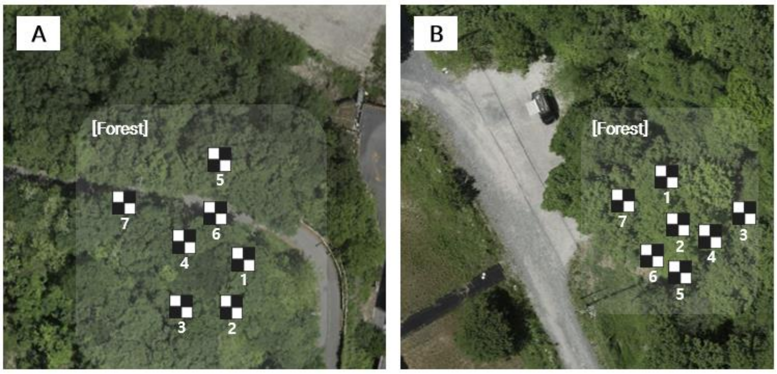


Figure 1: Placement of GCPs.

**Research results**

(1) Accuracy Assessment of Terrain Model Elevations by Flight Altitude

The accuracy of point cloud elevations acquired within the aerial targets was evaluated by comparing data from the L1 and L2 sensors with ground control point coordinates. In Area A, GNSS equipment was used to measure control point coordinates, and the root mean square error (RMSE) of the Z-values from the point clouds was calculated for each flight altitude (50 m, 80 m, 100 m, and 150 m).

The comparison between point clouds acquired from aerial targets beneath dense vegetation in the gently sloped forest (Area A) and GNSS control points revealed clear differences between the L1 and L2 sensors. The RMSE of the L1 sensor was 0.071 m at 50 m, 0.112 m at 80 m, 0.092 m at 100 m, and 0.132 m at 150 m (Table 1). In contrast, the L2 sensor achieved RMSE values of 0.041 m at 50 m, 0.046 m at 80 m, 0.054 m at 100 m, and 0.067 m at 150 m, consistently showing higher accuracy (Table 2).

Table 1: Vertical RMSE of L1 acquired on forest terrain(@50~150m height)

| **Point** | | **Coordinates by GNSS surveying** | | | **Observed coordinates of points** | **dz(m)** |
|---|---|---|---|---|---|---|
| | | **X(m)** | **Y(m)** | **Z(m)** | **Z(m)** | |
| 50m | 1 | 206187.411 | 328546.36 | 288.624 | 288.647 | -0.023 |
| | 2 | 206186.15 | 328538.031 | 289.053 | 289.064 | -0.01 |
| | 3 | 206176.133 | 328539.978 | 289.606 | 289.704 | -0.098 |
| | 4 | 206176.506 | 328550.639 | 289.214 | 289.323 | -0.109 |
| | 5 | 206185.164 | 328562.355 | 286.32 | 286.378 | -0.058 |
| | 6 | 206182.851 | 328555.002 | 286.72 | 286.815 | -0.094 |
| | 7 | 206166.608 | 328558.563 | 287.758 | 287.795 | -0.038 |
| RMSE | | | | | | 0.071 |
| … | … | … | … | … | … | … |
| | … | … | … | … | … | … |

Table 2: Vertical RMSE of L2 acquired on forest terrain(@50~150m height)

| **Point** | | **Coordinates by GNSS surveying** | | | **Observed coordinates of points** | **dz(m)** |
|---|---|---|---|---|---|---|
| | | **X(m)** | **Y(m)** | **Z(m)** | **Z(m)** | |
| 50m | 1 | 206187.411 | 328546.36 | 288.624 | 288.666 | -0.042 |
| | 2 | 206186.15 | 328538.031 | 289.053 | 289.089 | -0.035 |
| | 3 | 206176.133 | 328539.978 | 289.606 | 289.67 | -0.065 |
| | 4 | 206176.506 | 328550.639 | 289.214 | 289.279 | -0.065 |
| | 5 | 206185.164 | 328562.355 | 286.32 | 286.325 | -0.005 |
| | 6 | 206182.851 | 328555.002 | 286.72 | 286.729 | -0.009 |
| | 7 | 206166.608 | 328558.563 | 287.758 | 287.745 | 0.0127 |
| RMSE | | | | | | 0.041 |
| … | … | … | … | … | … | … |
| | … | … | … | … | … | … |

The differences in RMSE between the two sensors were 0.030 m at 50 m, 0.066 m at 80 m, 0.038 m at 100 m, and 0.065 m at 150 m. This indicates that the L2 sensor provided approximately 1.7–2.4 times greater precision than the L1 sensor. In particular, the smaller laser spot size and multi-return capability of the L2 sensor appear to enable the effective acquisition of precise and stable data even beneath dense vegetation.

Due to multiple reflections, the L1 sensor exhibited data loss in the mid-layer canopy, while the L2 sensor, which supports up to five returns, effectively captured laser signals in complex multilayer structures, thereby providing more precise point cloud data.

In Area B (steeply sloped forest with dense vegetation and flat terrain), aerial target point cloud data collected by the L1 and L2 sensors were analyzed. In the steeply sloped forest, the L1 sensor recorded RMSE values of 0.066 m at 50 m and 0.071 m at 80 m (Table 3).

Table 3: Vertical RMSE of L1 acquired on forest terrain

| **Point** | | **Coordinates by GNSS surveying** | | | **Observed coordinates of points** | **dz(m)** |
|---|---|---|---|---|---|---|
| | | **X(m)** | **Y(m)** | **Z(m)** | **Z(m)** | |
| 50m | 1 | 205310.270 | 329889.456 | 242.842 | 242.880 | -0.038 |
| | 2 | 205317.832 | 329892.594 | 242.948 | 243.003 | -0.055 |
| | 3 | 205322.715 | 329883.511 | 244.736 | 244.793 | -0.057 |
| | 4 | 205332.441 | 329885.79 | 246.629 | 246.775 | -0.146 |
| | 5 | 205326.994 | 329881.946 | 244.792 | 244.83 | -0.038 |
| | 6 | 205322.728 | 329876.567 | 243.413 | 243.410 | 0.003 |
| | 7 | 205319.065 | 329877.726 | 242.897 | 242.908 | -0.011 |
| RMSE | | | | | | 0.066 |

In comparison, the L2 sensor achieved RMSE values of 0.039 m at 50 m and 0.052 m at 80 m, with RMSE differences of 0.027 m and 0.019 m, respectively (Table 4). This demonstrates that the L2 sensor provided approximately 1.4–1.7 times higher precision than the L1 sensor.

Table 4: Vertical RMSE of L2 acquired on forest terrain

| Point | | Coordinates by GNSS surveying | | | Observated coordinates of points | dz(m) |
|---|---|---|---|---|---|---|
| | | X(m) | Y(m) | Z(m) | Z(m) | |
| 50m | 1 | 205310.270 | 329889.456 | 242.842 | 242.842 | -4E-04 |
| | 2 | 205317.832 | 329892.594 | 242.948 | 242.97 | -0.022 |
| | 3 | 205322.715 | 329883.511 | 244.736 | 244.773 | -0.037 |
| | 4 | 205332.441 | 329885.79 | 246.629 | 246.705 | -0.076 |
| | 5 | 205326.994 | 329881.946 | 244.792 | 244.814 | -0.022 |
| | 6 | 205322.728 | 329876.567 | 243.413 | 243.418 | -0.005 |
| | 7 | 205319.065 | 329877.726 | 242.897 | 242.946 | -0.049 |
| RMSE | | | | | | 0.039 |

The L1 sensor generated relatively sparse point clouds due to insufficient ground penetration of laser signals, resulting in data gaps. By contrast, the L2 sensor collected denser point clouds over the same area, minimizing data omission and capturing small ground undulations and slopes beneath the canopy with greater accuracy.

On flat terrain, the L1 sensor produced RMSE values of 0.031 m at 50 m and 0.038 m at 80 m (Table 5). The L2 sensor recorded RMSE values of 0.031 m at 50 m and 0.036 m at 80 m (Table 6), with minimal differences of 0.001 m and 0.002 m, respectively. This result indicates that on obstacle-free flat terrain, reliable point cloud data can be obtained even with the L1 sensor.

Table 5: Vertical RMSE of L1 acquired on flat terrain

| height | Coordinates by GNSS surveying | | | Observated coordinates of points | dz(m) |
|---|---|---|---|---|---|
| | X(m) | Y(m) | Z(m) | Z(m) | |
| 50m | 205293.6614 | 329876.747 | 242.083 | 242.087 | -0.004 |
| RMSE | | | | | 0.031 |
| 80m | 205310.270 | 329889.456 | 242.842 | 242.076 | 0.007 |
| RMSE | | | | | 0.038 |

Table 6: Vertical RMSE of L2 acquired on flat terrain

| height | Coordinates by GNSS surveying | | | Observated coordinates of points | dz(m) |
|---|---|---|---|---|---|
| | X(m) | Y(m) | Z(m) | Z(m) | |
| 50m | 205293.6614 | 329876.747 | 242.083 | 242.073 | 0.009 |
| RMSE | | | | | 0.030 |
| 80m | 205310.270 | 329889.456 | 242.842 | 242.076 | 0.007 |
| RMSE | | | | | 0.036 |

The L1 sensor data exhibited some height errors due to noise, whereas the L2 sensor produced less noisy and more precise point clouds. This difference is attributed to the L2 sensor's ability to utilize multiple returns and effectively filter noise during preprocessing. Therefore, on flat terrain, accurate 3D terrain modeling can be achieved either by employing the L2 sensor's multi-return data or by applying noise-filtering processes to L1 sensor data.

2) Point Density Comparison

Point density, measured by the number of collected points per unit area, influences the accuracy and quality of point cloud data for 3D modeling. To compare the point density of the L1 and L2 sensors at altitudes of 50m and 80m, we quantitatively analyzed the number of points reflected within a unit area (70cm x 70cm) beneath vegetation in a densely forested, steeply sloped area (Area B) and on flat, obstacle-free ground.

In the densely vegetated and steeply sloped forest, the difference in point density was clear. The L1 sensor captured 365 points at 50m and 143 points at 80m per unit area. In contrast, the L2 sensor collected 675 points at 50m and 204 points at 80m, demonstrating approximately 1.4 to 1.8 times higher point density than the L1 sensor (Table 7).

Table 7. Point density per unit area(70cm X 70cm) each altitude(@50m, @80m)

| LiDAR sensor | @50m (pts) | @80m (pts) |
|---|---|---|
| L1 | 365 | 143 |
| L2 | 675 | 204 |

On flat terrain, the L1 sensor collected 1,385 points at 50m and 492 points at 80m per unit area, while the L2 sensor acquired 3,014 points at 50m and 626 points at 80m (Table 8).

Consequently, the L2 sensor showed a 1.2 to 2.2 times higher point density than the L1 sensor. The L2 sensor's point density was about twice as high as the L1's at 50m, but the difference between the two sensors tended to decrease as the altitude increased.

Table 8. Point density per unit area(70cm X 70cm) each altitude(@50m, @80m)

| LiDAR sensor | @50m (pts) | @80m (pts) |
|---|---|---|
| L1 | 1,385 | 492 |
| L2 | 3,014 | 626 |

## Conclusions

Overall, a comprehensive comparison of the L1 and L2 sensors revealed that the L2 sensor can collect more stable and precise point cloud data even at high altitudes. The L2 sensor maintained data accuracy as the scanning altitude increased and was able to acquire point cloud data even at 150m. In contrast, the L1 sensor's point cloud data accuracy decreased with increasing altitude, and it was unable to acquire data at 150m. This is because the L2 sensor utilizes multi-return signal processing technology and a wider field of view to provide higher precision.

The experiments in both forested and flat areas showed that the L2 sensor demonstrated 1.2 to 2.2 times higher point density than the L1 sensor. Specifically, in the densely vegetated, steeply sloped forest, the L2 sensor effectively captured ground data using multi-return signals, minimizing the potential for data omission. In contrast, while the L1 sensor provided reliable data on simple, flat terrain, its performance was relatively degraded in complex forest environments.

Therefore, because the L1 and L2 sensors each have their own advantages and application scopes, it is necessary to select and operate the appropriate sensor based on the disaster site's terrain and data requirements. The L1 sensor is efficient for simple terrains like large, open areas, while the L2 sensor's multi-return technology is particularly valuable for supplementing data that can be easily missed in complex terrain, making it suitable for use in disaster situations within large-scale forest areas.

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