Accuracy Assessment of UAV LiDAR Compared to Traditional Total Station for Geospatial Data Collection in Land Surveying Contexts

Rami Tamimi, Charles Toth

SPIN Laboratory, Department of Civil, Environmental and Geodetic Engineering, The Ohio State University
225 Bolz Hall, 2036 Neil Ave, Columbus, OH 43210, USA – (tamimi.12, toth.2) @osu.edu.

KEY WORDS: LiDAR, Total Station, Ground Truthing, GNSS, Digital Terrian Modeling, Surveying

ABSTRACT:

Accurate surveying of vegetated areas presents significant challenges due to obstructions that obscure visibility and compromise the precision of measurements. This paper introduces a methodology employing the DJI Zenmuse L2 Light Detection and Ranging (LiDAR) sensor, which is mounted on a Matrice 350 RTK drone. The DJI Zenmuse L2 sensor excels at capturing detailed terrain data under heavy foliage, capable of collecting 1.2 million points per second and offering five returns, thus enhancing the sensor's ability to detect multiple surface responses from a single laser pulse. In a case study conducted near a creek heavily obscured by tree coverage, traditional aerial imaging techniques are found insufficient for capturing critical topographic features, such as the creek banks. Employing LiDAR, the study aims to map these obscured features effectively. The collected data is processed using DJI Terra software, which supports the accurate projection and analysis of the LiDAR data. To validate the accuracy of the data collected from the LiDAR sensor, traditional survey methods are deployed to ground truth the data and provide an accuracy assessment. Ground control points (GCPs) are established using a GNSS receiver to provide geodetic coordinates, which then assist in setting up a total station. This total station measures vertical and horizontal angles, as well as the slope distance from the instrument to positions underneath the tree coverage on the ground. These measurements serve as checkpoints to validate the accuracy of the LiDAR data, thus ensuring the reliability of the survey. This paper discusses the potential of integrating LiDAR data with traditional surveying data, which is expected to enhance the ability of surveyors to map environmental features efficiently and accurately in complex and vegetated terrains. Through detailed procedural descriptions and expected outcomes, the study aims to provide valuable insights into the strategic application of geospatial technologies to overcome common surveying challenges.

1. Introduction

The use of geospatial technologies has transformed surveying and mapping practice and standards. Traditional methods are precise but often face challenges with accessibility and efficiency in complex terrains such as dense forests or rugged landscapes (Li et al., 2019). Aerial survey technologies like LiDAR enable surveyors to overcome these challenges by capturing detailed topographical data and penetrating vegetative cover to reveal the earth's surface, tasks previously unachievable with traditional methods alone (Huylenbroeck et al., 2020).

Unmanned Aerial Vehicle (UAV) LiDAR is effective in environments where dense vegetation obscures the ground. It can generate accurate three-dimensional terrain models, crucial for creating Digital Terrain Models (DTMs) in areas where manual survey methods are impractical or environmentally prohibited (Hui et al., 2021). For ground truthing in GNSS-denied environments, traditional survey techniques such as the use of a total station are essential. These provide measurements where GNSS receivers are ineffective due to limited satellite visibility and maintain high accuracy necessary for comparing datasets from other platforms. By establishing control with GNSS outside the vegetated area and using a total station to traverse into under the canopy, surveyors can collect accurate ground measurements at specific points. These measurements then can serve as checkpoints to validate the precision of the UAV LiDAR data, ensuring its correct positioning and accuracy for projects requiring high precision on hard surfaces (Maldonado et al., 2020; Yun et al., 2021).

(Lin et al., 2019) conducted a quantitative analysis and found that UAV LiDAR achieves an RMSE of 0.1 meters in coastal terrain mapping, demonstrating high resolution and accuracy. The results highlight UAV LiDAR's potential to improve coastal management and planning by providing detailed terrain insights critical for addressing issues like coastal erosion. The study supports the use of UAV LiDAR as a robust and efficient alternative to conventional surveying, especially in areas with access challenges or where environmental preservation is essential.

(Salach et al., 2018) conducted an accuracy assessment of point clouds obtained from LiDAR and dense image matching using UAV platforms for Digital Terrain Model (DTM) creation. Their study systematically compared these UAV-derived point clouds to reference data collected through traditional ground-based survey methods. The findings showed that LiDAR-based point clouds exhibited an RMSE of approximately 0.05 meters. While this suggests good accuracy, dense image matching can achieve sub-centimeter accuracy under optimal conditions. In environments with dense canopy coverage, however, dense image matching often struggles, resulting in lower quality outputs and reduced accuracy compared to LiDAR, which consistently maintains higher performance under such conditions. These results underscore the effectiveness of UAV LiDAR for precise topographic mapping and its superiority over image-based methods in terms of accuracy for DTM creation. The study advocates for the integration of UAV LiDAR into geospatial data collection workflows, particularly in contexts requiring high precision and efficiency.

(Józków, Toth et al., 2016) conducted a study on UAV topographic mapping utilizing a Velodyne LiDAR sensor. Their approach involved mounting the LiDAR sensor on a UAV to collect topographic data across varied landscapes. They compared the LiDAR derived data to ground truth data obtained through traditional surveying techniques. The results indicated that the Velodyne achieved an RMSE of approximately 0.05 meters in areas with optimal conditions, demonstrating its high precision and effectiveness in producing accurate topographic maps.

https://doi.org/10.5194/isprs-archives-XLVIII-2-2024-421-2024 |

While the DJI Zenmuse L2 is a relatively new sensor, not much research has been published yet about the performance of this LiDAR sensor. (Sun et al., 2024) reviewed the application of UAVs in landslide investigation and monitoring, highlighting the capabilities of the L2 LiDAR sensor in such contexts. The study assesses the precision and reliability of the L2 sensor for creating detailed topographical maps critical for landslide analysis. The results demonstrate that the L2 LiDAR sensor achieves an RMSE of approximately 0.06 meters, showcasing its high accuracy and effectiveness in capturing terrain changes over time. The review strongly supports the use of UAVs equipped with the L2 LiDAR sensor for continuous and efficient landslide monitoring, emphasizing its potential to enhance predictive analytics and risk management in vulnerable areas.

This paper details the workflow and data analysis process, demonstrating how LiDAR data collected from the L2 using a UAV can be evaluated against traditional total station measurements. UAV LiDAR provides a method to capture extensive geographical data, which is then compared to the precise measurements from total station surveys. Such assessments are crucial for applications in urban planning, environmental conservation, infrastructure development, and disaster management, where the precision and reliability of geographical data are paramount (Macedo et al., 2023). By implementing a detailed accuracy assessment strategy, this study highlights the benefits and limitations of using UAV LiDAR alongside traditional surveying techniques in modern surveying projects, providing insights into improving data integrity and survey efficiency.

2. METHODOLOGY

2.1 Study Aera

The study area is located at an abandoned golf range in Inkster, Michigan, situated off Michigan Ave sized at approximately 30 acres or 12 hectares. The site features a varied landscape, including a main road, an open golf range, and densely wooded areas leading to a creek. These elements create a diverse terrain that presents physical challenges and productivity issues for data acquisition, especially in extensive mapping projects where dense vegetation limits ground visibility. Figure 1 shows an aerial view of the site.

The main road requires high-precision surveying with accuracy up to one centimeter to support infrastructure and traffic safety. In contrast, the golf range and the areas beneath the tree canopy leading to the creek allow for lower accuracy. This difference in precision requirements makes the golf range an ideal location to demonstrate the effectiveness of multi-sensor integration. The project aims to show how integrating various surveying sensors can be effectively applied across areas with varying accuracy needs, optimizing resource allocation and enhancing survey efficiency.

2.2 Data Collection

2.2.1 DJI M350 RTK (L2 LiDAR sensor)

The survey used the DJI Matrice 350 (M350) RTK drone, known for its integration with Real-Time Kinematic (RTK) positioning systems to enhance navigational accuracy, essential for precision surveying tasks. Equipped with the DJI Zenmuse L2 LiDAR sensor, the M350 was configured to leverage the sensor's capabilities. This feature is critical for penetrating vegetation and capturing the underlying topography accurately. Mission planning was conducted using DJI's flight planning software, Pilot 2, to ensure comprehensive coverage of the golf range and adjacent areas.

Figure 1. Aerial view of the study area.

The Zenmuse L2 sensor automatically performs self-calibrations of its Inertial Measurement Unit (IMU) during flight, supplemented by RTK corrections from the drone's GNSS to enhance positional accuracy crucial for high-quality 3D mapping. This continuous calibration process addresses and corrects any drift or errors in the IMU measurements, while RTK corrections ensure precise positioning, maintaining the sensor's trajectories throughout the survey operation. These adjustments are essential for accurately aligning the LiDAR data with real-world coordinates, ensuring consistent and reliable mapping outputs. Additionally, the simultaneous localization and mapping (SLAM) technology employed by the sensor adjusts to the recalibration, adapting its spatial understanding to maintain accuracy in creating and updating the map in real time, even under varying flight conditions. This integrated approach of IMU calibration, RTK corrections, and SLAM adjustments ensures

https://doi.org/10.5194/isprs-archives-XLVIII-2-2024-421-2024 | © Author(s) 2024. CC BY 4.0 License.

that the mapping outputs remain highly accurate and reflective of the actual terrain.

During the mission, the M350 RTK executed multiple flight lines according to the planned route. The L2 collected data, utilizing its multi-return capability to effectively capture detailed terrain features beneath the vegetation. RTK continuously corrects the drone's trajectory to within a few centimeters of accuracy, significantly enhancing the alignment and precision of the LiDAR data.

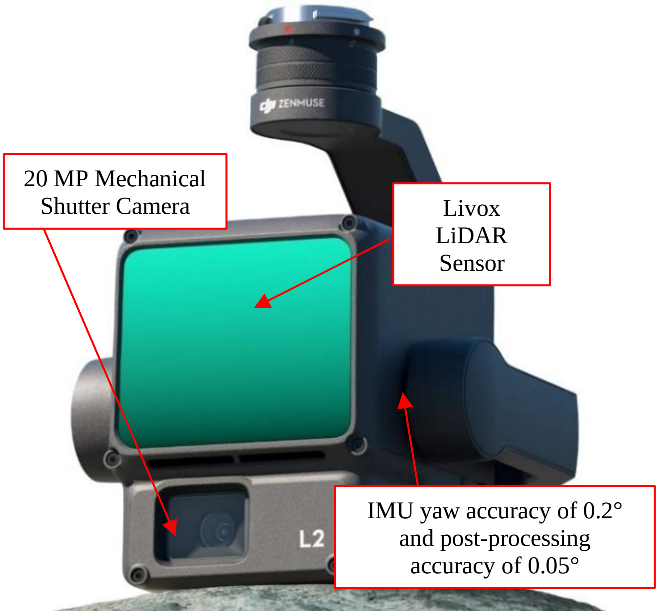

Figure 2. DJI Zenmuse L2 LiDAR Sensor

2.2.2 Ground Truthing

To support the georeferencing of the dataset, a total of five ground control points is established using a GNSS receiver. The GNSS receiver employed for this task is the Leica GS18I, notable for its multi-band data collection capabilities, ensuring robust and reliable positioning even under challenging conditions such as dense canopies or near large structures that might interfere with multipathing. It also houses a built-in IMU for tilt compensation. This feature allows surveyors to collect accurate geospatial data even when the receiver is not perfectly level, enhancing the flexibility and speed of data collection in the field.

Additional survey controls are established using the GNSS receiver to facilitate the setups of total station for deeper penetration into forested areas where satellite observations may be difficult. The total station used was a Leica TS16, known for its 1 arcsecond precision, giving sub-centimeter level accuracy up to 1 kilometer of range. These setups are strategically placed to allow the total station to take precise measurements at various checkpoints within the forest. These points are essential for validating the accuracy of the LiDAR data collected by the L2 sensor, particularly in areas near the creek banks where LiDAR's ability to penetrate vegetation is tested. The DTM generated from the L2 sensor will be compared against the measurements obtained from ground truthing. This comparative analysis is critical to assess the integrity and accuracy of the LiDAR data. By aligning the LiDAR-derived DTM with ground-truthed data from the total station, discrepancies can be identified and analyzed, providing insights into the sensor's performance and the overall reliability of the survey data.

The total station was used to collect approximately 400 checkpoints across different terrain conditions within the study area. About 350 of these points were collected on the road as a full traditional topographic survey was performed for this project, therefore all points collected on the road are used for analysis. 50 points were collected within the forested area, which presented more challenging conditions for data collection due to the tree bark obstructions. For the purposes of this analysis, all these points are utilized as ground truth data. However, they are analyzed separately: the points on the road will be referred to as 'road checkpoints' and those in the forest as 'forest checkpoints'. This separation will allow for a more nuanced comparison of the LiDAR data's accuracy across distinctly different environments within the project site and to see if areas with multiple returns have a higher error than in areas with single returns. Figure 3 shows the locations at which all 400 points were taken with the total station.

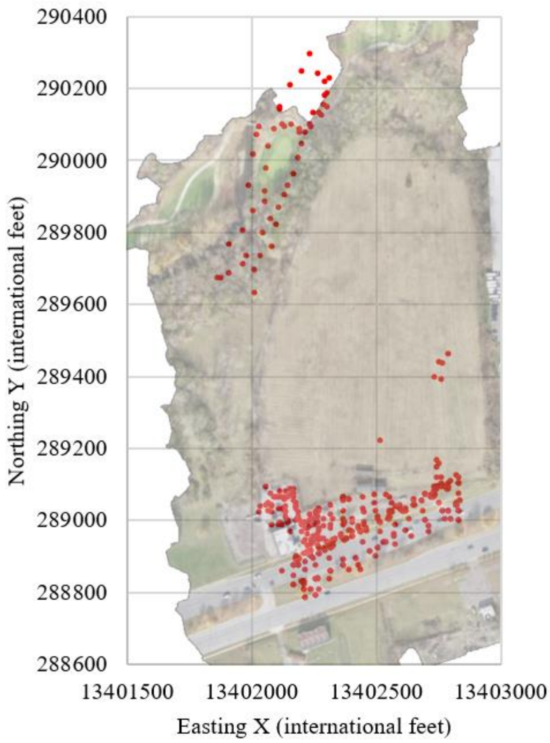

Figure 3. Checkpoints collected with a Total Station

2.3 Data Processing

2.3.1 UAV LiDAR processing in DJI Terra

LiDAR data from the DJI Zenmuse L2 sensor is processed using DJI Terra, which projects the data into the NAD 83 Michigan South state plane coordinate system, aligning it with local geospatial standards for integration with other datasets. GCPs, acquired by the GNSS receiver, are integrated within DJI Terra to ensure the vertical accuracy of the LiDAR data are confirmed against the NAVD88 vertical datum using GEOID18 orthometric heights. During post-processing, DJI Terra displays all sensor returns, allowing assessment of the LiDAR's penetration through tree coverage near the creek. Figure 4 illustrates the return visualization of the point cloud, with single returns shown in blue and multiple returns in other colors. The software's visualization tools enable detailed examination of the point cloud, highlighting successful terrain captures beneath the canopy and identifying any discrepancies. Once data quality is verified and necessary adjustments made, the processed LiDAR data is utilized to create a DTM using Pix4Dsurvey.

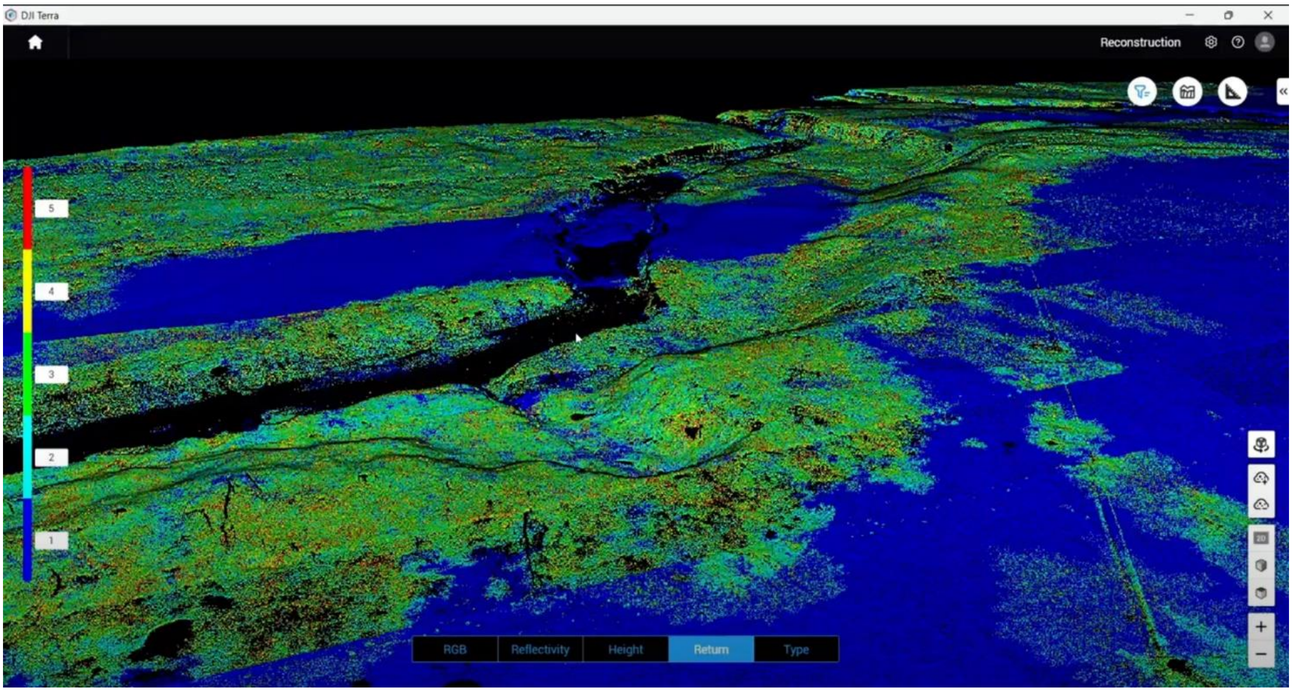

Figure 4. Return Visualization Point Cloud in DJI Terra;
Blue: 1 return, Cyan: 2 returns, Green: 3 returns, Yellow: 4 returns, & Red: 5 returns

2.3.2 Generating DTM

The initial step in generating the DTM involved importing a ground classified point cloud consisting of approximately 235,000,000 points, a density of about 725 points/m^2, into Pix4Dsurvey setting the grid spacing to 30 centimeters. Figure 5 shows the points generated beneath the tree coverage on the terrain when the non-ground points in the point cloud are removed. After processing in Pix4Dsurvey, Microsoft Excel is used for statistical analysis of the DTM data.

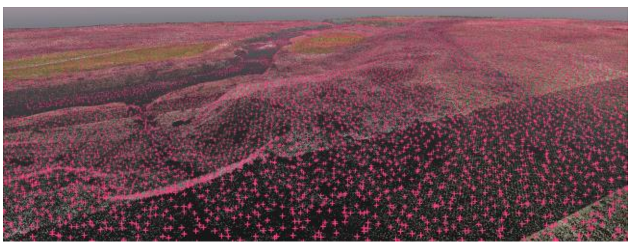

Figure 5. DTM points (marked by pink plus symbol) on the ground classified point cloud.

3. RESULTS

3.1 Accuracy Analysis

The nearest DTM point to each ground truth point is matched using the shortest horizontal Euclidean distance from surrounding DTM points. This allows us to compare the elevations of each of these points to evaluate the accuracy of the DTM generated from the LiDAR data (Suwandart al. 2020).

Once the points from the total station are matched with a DTM point, we can then begin analyzing the accuracy of the LiDAR data. We calculate the vertical difference by taking the absolute value of the difference for each pair of matched points to assess the vertical accuracy of the LiDAR data. The formula for vertical difference:

$$v = |Z_L - Z_{TS}| \quad (1)$$

where v is the vertical difference, Z_L is the elevation of the LiDAR DTM, and Z_{TS} is the elevation of the total station ground truth.

Following general practice, the absolute value is taken for vertical differences to ensure proper averaging. Summing vertical distances that include a mix of positive and negative values could lead to cancellation, giving a misleading representation of the average difference, though in this case, any vertical bias becomes apparent, indicating whether the total station or LiDAR data consistently measures higher or lower than its compared dataset. This method prevents false positives in the summation of distances and clarifies the directional bias in measurements.

Finally, the root mean square error (RMSE) will measure the combined vertical errors, emphasizing the accuracy of the LiDAR data in capturing terrain elevations. The formula used for RMSE is as follows:

$$RMSE = \sqrt{\frac{\sum v^2}{n}} \quad (2)$$

where v is the vertical difference, and n is the number of matched points.

3.2 Road Ground Truth

The road environment offered ideal conditions for LiDAR operations in a perfect scenario, as the absence of physical barriers allowed for optimal sensor performance and the generation of highly accurate DTMs. The RMSE between the DTM LiDAR data and the ground truth total station measurements was calculated to be 0.07 meters. This is a realistic result, as the Zenmuse L2 ranging accuracy is 4 cm, so adding the georeferencing error, 7 cm seems to represent a nearly optimal performance. Figure 5 shows a graphical representation of all the points and the vertical differences. The RMSE shows the reliability of the DJI L2 sensor in surveying open areas like roads using a single return. An error margin like this is considered acceptable for preliminary surveys and could reduce the need for extensive ground surveys, saving time and resources while maintaining accuracy standards.

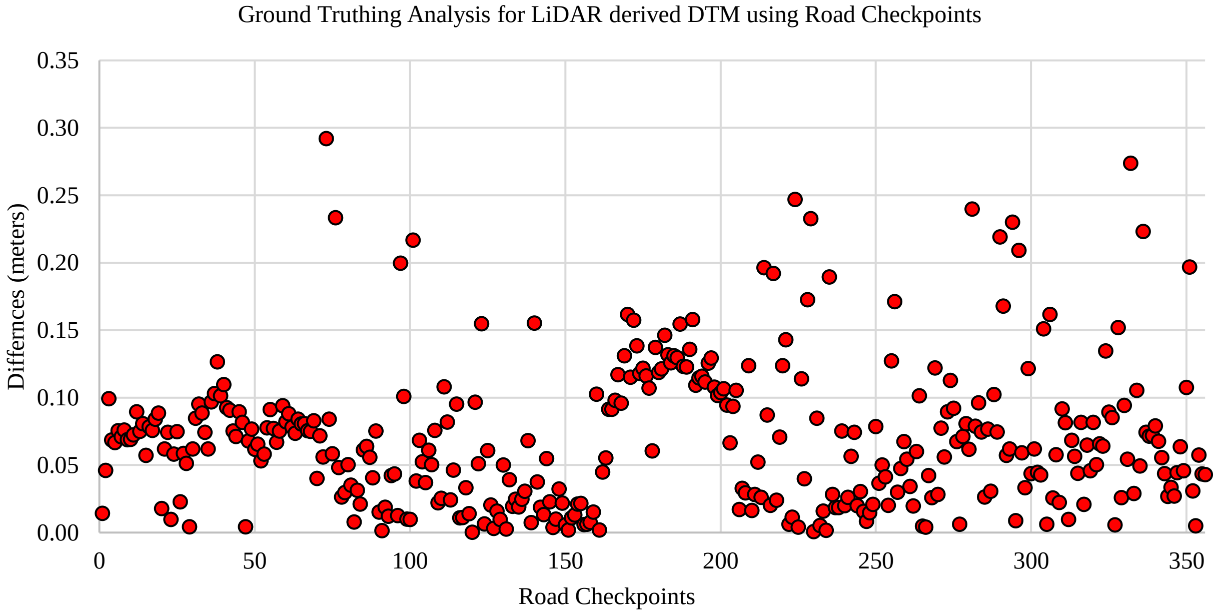

Figure 5. Vertical differences of the DTM points at road-based checkpoints.

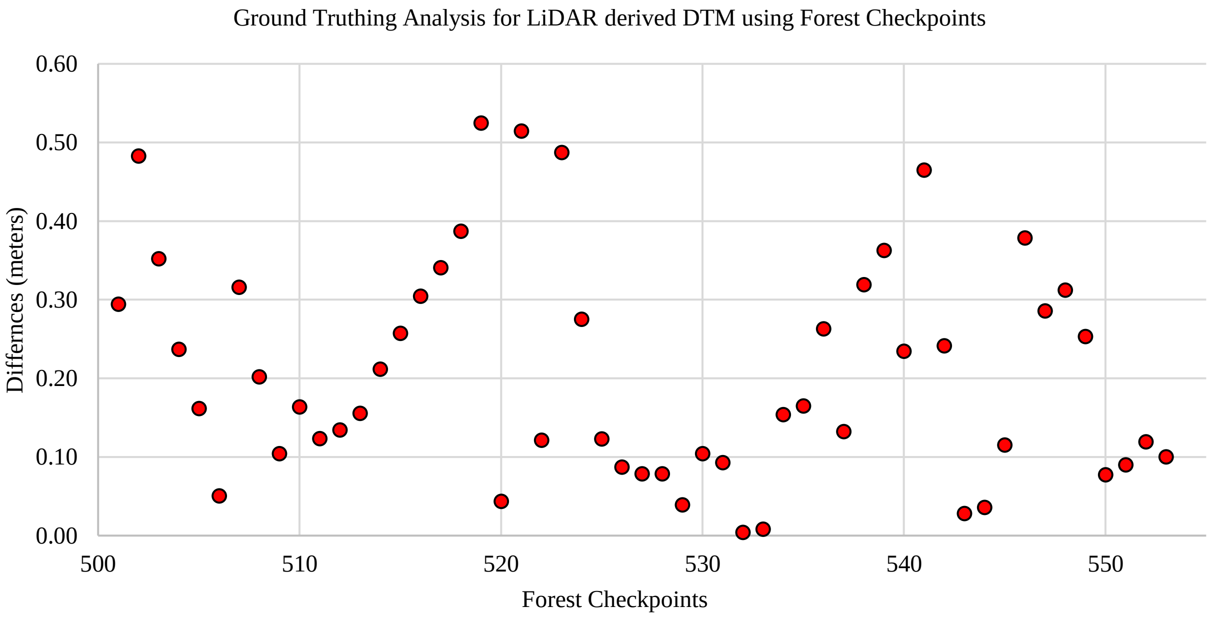

Figure 6. Vertical differences of the DTM points at forest-based checkpoints.

3.3 Forest Ground Truth

Surveying within forested areas presents challenges due to obstructions from trees with dense foliage and branches, affecting LiDAR sensor performance. Even with a sensor that multiple returns, second, third, fourth, and fifth returns are not always as reliable as the first return, complicating data accuracy. The RMSE for forest checkpoints was noted at 0.21 meters. Despite many points exhibiting errors below 0.1 meters, some segments of points showed increased errors escalating to approximately 0.5 to 0.6 meters. This rise in error may stem from sensor issues and/or data processing inaccuracies. While the overall RMSE remains within acceptable limits for forestry and environmental management applications, the detailed examination of errors, as shown in Figure 6, underscores the need for advanced strategies to improve this LiDAR sensor's reliability in dense vegetative cover.

4. Discussion and Conclusion

The results from this study highlight the capabilities and limitations of UAV LiDAR technology in varying survey environments. On open roads, the LiDAR sensor achieved a low RMSE of approximately 0.07 meters, demonstrating its potential as an effective alternative to traditional survey methods for infrastructure projects using mainly its first return. However, in forested areas with dense canopy, the RMSE increased to approximately 0.21 meters. This indicates challenges due to limited penetration to foliage, impacting accuracy. Notably, errors significantly increased in certain segments, suggesting issues with sensor performance and/or data processing. This would be an excellent area of exploration seeing the accuracy levels of the various returns in forested areas. To improve UAV LiDAR's accuracy validation in forested settings, increasing the number of GCPs could improve the data.

Conclusively, while UAV LiDAR with the DJI Zenmuse L2 shows great promise for topographical data collection in clear and vegetated terrains, improvements are needed for ensuring the integrity of the data. As UAV LiDAR technology advances, integrating these improvements are expected to enhance survey accuracy and efficiency.

Acknowledgement

We extend our sincere gratitude to DJI, Pix4D, and Leica Geosystems for their invaluable support and provision of essential hardware and software for this project. Their generosity has greatly contributed to the success and advancement of our research in mobile mapping. We are incredibly grateful for their involvement and partnership in making this endeavor possible.

References

Li, Hui, et al. "Mapping of river terraces with low-cost UAS based structure-from-motion photogrammetry in a complex terrain setting." Remote Sensing 11.4 (2019): 464.

Huylenbroeck, Leo, et al. "Using remote sensing to characterize riparian vegetation: A review of available tools and perspectives for managers." Journal of environmental management 267 (2020): 110652.

Hui, Zhenyang, et al. "A mean shift segmentation morphological filter for airborne LiDAR DTM extraction under forest canopy." Optics & Laser Technology 136 (2021): 106728.

Hussein, S., and K. Yaseen. "Surveying with GNSS and Total Station: A Comparative Study." Eurasian J. Sci. Eng 7 (2021): 59-73.

Maldonado, Gustavo, et al. "Point-Cloud Models of Historical Barns–Spatial Discrepancies of Laser Scanning versus Robotic Total Station." ASC 2020 56th Annual ASC International Conference, (Epic Series in Built Environment, vol 1). 2020.

Yun, Ting, et al. "Individual tree crown segmentation from airborne LiDAR data using a novel Gaussian filter and energy function minimization-based approach." Remote Sensing of Environment 256 (2021): 112307.

Lin, Yi-Chun, et al. "Evaluation of UAV LiDAR for mapping coastal environments." Remote Sensing 11.24 (2019): 2893.

Salach, Adam, et al. "Accuracy assessment of point clouds from LiDAR and dense image matching acquired using the UAV platform for DTM creation." ISPRS International Journal of Geo-Information 7.9 (2018): 342.

Jóźków, Grzegoz, Charles Toth, and Dorota Grejner-Brzezinska. "UAS topographic mapping with Velodyne LiDAR sensor." ISPRS annals of the photogrammetry, remote sensing and spatial information sciences 3 (2016): 201-208.

Sun, Jianwei, et al. "Unmanned Aerial Vehicles (UAVs) in Landslide Investigation and Monitoring: A Review." Drones 8.1 (2024): 30.

Macedo, Marcia, and Bianca Ferreira. "Use of Advanced Technologies for Topographic Surveys in Civil Construction." J. Mgmt. & Sustainability 13 (2023): 17.

Suwanda, R., Zulfahmi Syahputra, and Elvi M. Zamzami. "Analysis of euclidean distance and manhattan distance in the K-means algorithm for variations number of centroid K." Journal of Physics: Conference Series. Vol. 1566. No. 1. IOP Publishing, 2020.