Development of Road Geometric Scanner Using Slamtec RPLiDAR A3

Louise Anne QUILAY [a], Lea BRONUELA-AMBROCIO [b]

[a, b] Institute of Civil Engineering, University of the Philippines, Diliman, Quezon City, 1101, Philippines
[a] E-mail: lpquilay@up.edu.ph
[b] E-mail: lbbronuela@up.edu.ph

Abstract:

Cross slope is a geometric feature of pavement surfaces which is the transverse slope with respect to the horizon. It is designed to provide a drainage gradient so that water will run off the surface to a drainage system. Even if highway pavements are well designed and constructed, they may require proper maintenance since different distresses like potholes, map cracking, raveling, and depression may occur in the pavement. These distresses are caused primarily by moisture, seepage of water and poor drainage. Hence, ponding of water on roads should be eliminated to reduce road distresses. Cross slopes are already being monitored in other countries such as the United States and China and the most common method in monitoring is LiDAR. The general objective of this research is to provide a tool that can assess the cross slope, width, and longitudinal profile of newly constructed and existing roads. Cross slopes were measured using LiDAR and the configuration featured the LiDAR being mounted to a vehicle together with a gimbal and a camera. The set-up was tested on a small scale road stretch (UP academic oval) and the data gathered were used as the criterion in the development of the tool. A user-friendly tool that can evaluate the road geometry (cross slope, width, and longitudinal profile) was successfully developed and further applied in some areas of Metro Manila. The data were validated using leveling, the conventional way of measuring pavement properties and statistical analysis was performed. It was concluded that there is no significant difference between the two methods in measuring the cross slopes. In addition, the accuracy of the tool developed was 76.6 %. Based on the results, it can be concluded that all of the road stretches that were analyzed are below the standard prescribed slope and it was visualized using a color-coded map. It is recommended to analyze the graph of the results to further refine the measured cross slopes of the road. Since there are a lot of factors that may affect the computation of the cross slopes such as obstruction from the car and vehicles from other lanes, it would be better to modify the program relating to data clipping every analysis.

Keywords: cross slope, road distress, LiDAR, pavement design, road geometry

1. INTRODUCTION

1.1 Background of the Study

Roadway geometry is a critical element of designing and planning for all types of roadway projects (Baffour, 2002). Cross slope or transverse slope with respect to the horizon, horizontal curves and the longitudinal profile or grade are major characteristics of the roadway geometry (Baffour, 2002). Grade and cross slope are used in several transportation applications, such as stopping and passing sight distance, roadway capacity, and modeling drainage patterns (Souleyrette, 2003). A sufficient amount of cross slope is necessary for effective removal (drainage) of stormwater from a pavement surface for traffic safety during periods of rainfall. In the Philippines, the minimum design standards of cross slope based on DPWH for Portland cement concrete pavement is 1.5% and 2.0% for Asphalt Concrete Pavement (ACP). In addition, the average cross slopes that are being implemented in other countries range from 1.5 % to 2.5 % which are nearly the same with the Philippines.

Well-designed highway pavements can still develop different types of distresses, such as potholes, map cracking, raveling, and depression, etc. if proper drainage gradient is not provided. These distresses are caused primarily by moisture, seepage of water and poor drainage (Nyein, 2019). Pavement cross slope should be one of the geometric designs that must be checked since it was found to affect water depths significantly (Gallaway, 1971). Factors that may affect the deterioration of pavements are environment, material characteristics, traffic volume, type of design standards, pavement age, and pavement construction quality (Hafizyar, 2020). Permanent deformation of the roadway will alter the cross slope, which in turn impacts the service performance of the highway. In India wherein several road distresses are present, it was observed that the side drainages were not maintained, cleaned and even absent in some places (Sorum, Neero & Guite, 2007). Moreover, pavement failure causes in North Cyprus are inadequate drainage facilities, poor design and construction, infiltration of surface runoff to the underlying course, thickness of asphaltic cement and poor soil material at some sections of the roads (Hafizyar, Rustam, Karimi, et al., 2020).

Cross slopes are already being monitored in other countries. For instance, ensuring adequate cross slopes on South Carolina highways and interstates is an important safety practice. South Carolina is already seeking other methods from traditional methods to collect accurate cross slope data. They tried to evaluate the use of Mobile Terrestrial LiDAR Scanning (MTLS). In addition, long term cross slope variation was studied in China since it affects the pavement drainage and has an adverse effect on vehicle operation safety (Miao, 2022). Here in the Philippines, design standards of cross slopes are provided in creating roads. However, there is no current method in monitoring the cross slopes of roads after the construction period. Last 2022, around 10,330 square meters of potholes were patched during the rainy season. If the roads with these potholes have adequate cross slopes, there will be no potholes that need to be patched in the first place. In addition, these patches will further alter the drainage gradient of the roads which will further lead to other types of road distress, not to mention the discomfort it brings to the road users. In conclusion, ponding of water on roads should be eliminated to reduce road distresses and this can be achieved by ensuring adequate cross slopes of roads.

1.2 Problem Statement

Inadequate pavement cross-slope will cause ponding of water on the pavement surface that can further lead to road distresses and early deterioration of roads. In addition, there are no guidelines and tools available to monitor the cross slope of existing pavement in the Philippines. Hence, this research aims to provide a cross slope monitoring tool that can be used to assess the compliance of existing roads with the standard.

1.3 Research Objectives

To solve the problems identified above, this study mainly aimed to provide a tool that can assess the cross slope, width, and longitudinal profile of newly constructed and existing roads. Specifically, this general objective was achieved through:

1. conducting a one-kilometer preliminary survey using LiDAR to gather 3D point data,
2. developing a program that can evaluate the road geometry (cross slope, width, and longitudinal profile),
3. validating the accuracy of the tool developed compared to the conventional method (leveling), and
4. mapping out the results of cross-slopes compared with the standard prescribed slope of roads.

2. LITERATURE REVIEW

2.1 Road Distresses

Better and efficient transportation system is affected by a large number of causes and one of them is the distress developed on the pavement during its service and resulting in premature failure of the pavements (Khan, 2013). A study by Nyein Nyein Thant and Soe Soe War discussed the distress patterns, causes and maintenance of flexible pavement. There are numerous distresses found in the road and each of them has different causes. This study says that potholes, map cracking, raveling, depression, and delamination are caused by moisture, seepage of water and poor drainage. This study proved that ponding of water on roads should be eliminated to reduce road distresses. Moreover, a case study by Hafizyar in Turkish Republic of Northern Cyprus on asphalt pavement distress evaluated the condition of asphalt pavement distresses due to maintenance planning and long-term strategy. Surveying was conducted from Lefkosa to Magosa City. It was concluded that pavement failure causes in North Cyprus are inadequate drainage facilities, poor design and construction, infiltration of surface runoff to the underlying course, thickness of asphaltic cement and poor soil material at some sections of the roads.

2.2 Cross Slope

It is important to determine which primarily cause the ponding of water in pavement to address the road distresses problems. In a study conducted by Gallaway in Texas, the effect of rainfall intensity, pavement cross slope, surface texture, and drainage length on pavement water depths were analyzed. Nine different types of surfaces were tested and rainfall of uniform intensity was applied to the surface. Water depth measurements were taken at regularly spaced drainage lengths for various combinations of rainfall intensity and pavement cross slope. Multiple regression analyses were used to determine the best fit of the data and he concluded that pavement cross slope was found to affect water depths significantly.

Even though design standards for cross slopes are already provided, researchers are still considering increasing the cross slope on roadway travel lanes. A research of Hilldebrand and Morrall in Alberta, Canada studied this problem to better accommodate climate change impacts such as rainfall intensity, duration, and frequency. This study says that cross slopes of greater than 2.0% in many countries and New Brunswick have not resulted in operational problems of heavy trucks with a high center of gravity crossing the crown line. In addition, cross slopes of up to 3.0% shed water approximately 23 to 42% faster than cross slopes of 1.5 – 2.0% and are a countermeasure to mitigate hydroplaning. This study was supported by Hassan Mahdy and Sherif Kamal who studied the minimum acceptable cross slopes of asphalt roads for drainage consideration. They also recommended that a higher pavement cross slope should be used if the rain intensities are greater than 40 mm. Larger value for the cross slope, compared with the cross slope value based on sheet flow depth, may be preferable to reduce the probability of water accumulation in the pavement ruts. (Goven, 1999).

Variation in road cross slope with service life affects the pavement drainage and has an adverse effect on vehicle operation safety (Miao, 2022). A study by Miao, Xu and Gao analyzed a cross-slope variation prediction method influenced by the coupling effect of traffic load and soil consolidation, considering characteristics of embankment to cover the shortage for insufficient consideration of compacted embankment. They concluded that the long-term settlement was mostly from the consolidation of natural soft subsoil, while the cross-slope variation was mainly affected by traffic load. Moreover, variation in the cross slope of highway in soft soil areas mainly occurs within 1 year of operation.

2.3 Methodologies in Monitoring

Many techniques are used for acquiring roadway cross slope including as-built plans, photogrammetry using high-resolution ortho images, conventional surveying, Global Positioning System (GPS), remote sensing data such as USGS Digital Elevation Models (DEMs), measuring with digital Gyroscope, advanced electronic surveying (Souleyrette, 2003; Baffour, 2002). Photogrammetry is an accurate method, which takes less time because after collecting the control points, most of the work can be conducted in the office. However, collecting high resolution ortho-rectification of aerial imagery is expensive (Souleyrette, 2003). Mobile mapping method is vital since vehicle based laser scanners allow fast processing of long corridors. Such information is needed in road 3D modeling, 2D and 3D navigation data.

Another method for data collection is LiDAR (Light Detection and Ranging) which uses lasers for capturing data instead of photographs. The lasers are used to generate a high density point cloud to aid in digital surface models.

While there are traditional methods in surveying the cross slope of roads, new and advanced methods in measuring road geometry are being practiced and tested for accuracy since the traditional method is time consuming and poses a safety risk to surveyors while they are on-road during the collection process (Souleyrette, 2003). A study by Alireza Shams evaluated the Mobile Laser Scanning (MLS) systems in terms of the accuracy and precision of collected cross-slope data. Mobile laser scanning (MLS) systems provide a rapid, continuous, and cost-effective means of collecting accurate 3D coordinate data along a corridor in the form of a point cloud. The results indicate the difference between ground control adjusted and unadjusted LiDAR derived cross-slopes, and field surveying measurements less than 0.19% at a 95% confidence level. This level of accuracy meets suggested cross-slope accuracies for mobile measurements (±0.2%) and demonstrates that mobile LiDAR is a reliable method for cross-slope verification.

In addition, a study by Sarasua, Ogle and Davis in 2018 proved the feasibility of Mobile Terrestrial Light Detection and Ranging (LiDAR) Scanning (MTLS) in comparison to manual data collection methods to obtain cross slope and estimate pavement material quantities. This study provides a wide-ranging technical and economic evaluation of multiple mobile scanning systems in terms of accuracy and precision of collected cross slope data and procedures to calibrate, collect, and process data. The research approach covered various work elements including detailed profile, alignment and cross section comparisons, and ground proofing using conventional survey methods.

While it is acknowledged that LiDAR technology has been widely used in previous studies to measure road cross-slope, this research distinguishes itself through several novel contributions. Firstly, the approach employed in this study is designed to be cost-effective and accessible. Unlike traditional LiDAR setups, which can be expensive and require specialized equipment and expertise, the method developed here is significantly more affordable and easier to operate, making it more practical for broader applications, including those with limited resources. Moreover, a key innovation of this research lies in the development of specialized software that enables instant data analysis from LiDAR outputs. This software streamlines the processing of cross-slope measurements, allowing for real-time or near-real-time assessment without the need for extensive post-processing. This capability not only enhances the efficiency of data collection and analysis but also provides immediate insights that can be critical in time-sensitive situations. By integrating cost-efficiency, ease of operation, and real-time analysis, this study offers a novel and practical approach to cross-slope measurement that addresses some of the limitations associated with existing methodologies.

2.4 Cross slopes monitoring in other countries

Other countries are already monitoring the pavement cross slope but mainly for the purpose of eliminating hydroplaning to reduce accidents brought by water ponding. While different studies showed that water ponding, moisture, seepage of water and poor drainage are the major causes of road distresses, there are no studies in the country that analyze the relationship between these two.

In South Carolina, ensuring adequate cross slopes on highways and interstates is an important safety practice. When cross slopes are too flat, too steep, or vary across the travel lanes, a number of safety issues can occur such as hydroplaning, loss of control, and run-off-road crashes (Sarasua, 2018). South Carolina is already seeking other methods from traditional methods to collect accurate cross slope data. They tried to evaluate the use of Mobile Terrestrial LiDAR Scanning (MTLS) and proved the reliability of this method. In addition, long term cross slope variation was studied in China since it affects the pavement drainage and has an adverse effect on vehicle operation safety (Miao, 2022).

3. METHODOLOGY

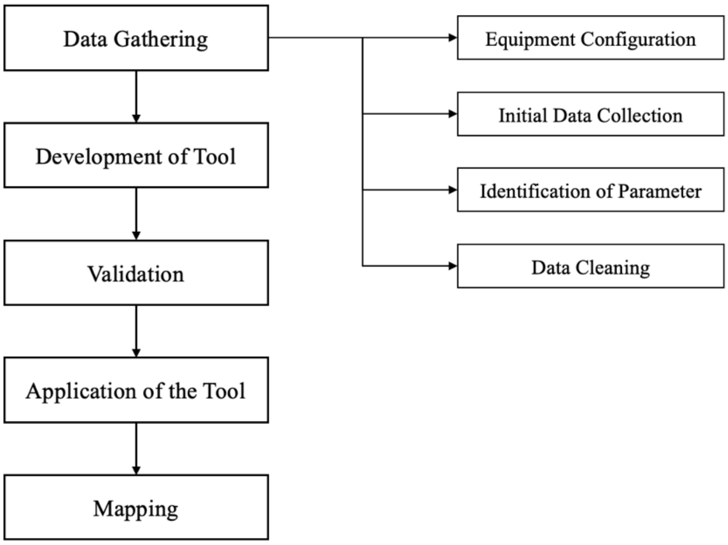


Figure 1. Methodological Framework

3.1 Data Gathering

3.1.1 Equipment Configuration

The study utilized the Slamtec RP Lidar A3 for cross-slope measurements. This particular LiDAR device was selected due to its balance of affordability, ease of integration, and sufficient technical specifications for the objectives of this research. It offers a scanning frequency of up to 16,000 samples per second and a range of up to 25 meters, making it suitable for detailed measurements within the study's scope. When compared to other LiDAR devices used in previous studies, the Slamtec RP Lidar A3 provides a more accessible option without sacrificing necessary accuracy for cross-slope measurement. While high-end LiDAR systems might offer greater range and higher resolution, they also come with significantly higher costs and operational complexity.

Figure 2. Equipment Configuration

The configuration featured the LiDAR being mounted at the back of a vehicle together with a gimbal and a camera. The problem with the LiDAR mounted at the back of a vehicle alone is that it would be leveled to the slope of the road together with the car. This problem was addressed by adding a gimbal to the configuration by eliminating the dependency of LiDAR's level to the vehicle and instead benchmark its level to the horizontal axis (0 degrees). The camera on the other hand, served as a reference which visually identified the location of a single data point.

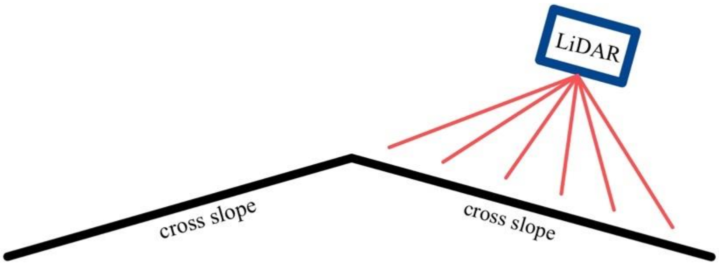


Figure 3. Equipment Configuration without Gimbal

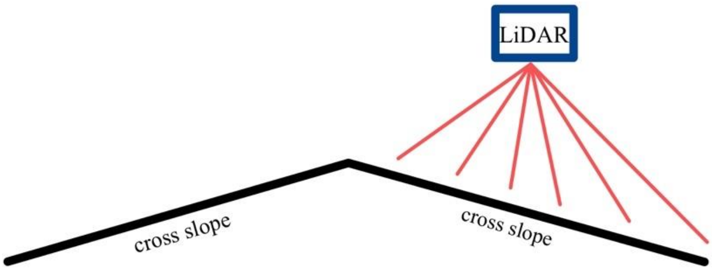


Figure 4. Equipment Configuration with Gimbal

3.1.2 Initial Data Collection

It was suggested to test the equipment configuration on a small-scale road stretch to simplify the experimental study. The preliminary application of the experimental set-up was done at the University Avenue of the University of the Philippines Diliman, Quezon City. Some parts of the road stretch were closed to motor vehicles which entails little to no traffic, making the application of the experiment easier for the researcher to implement. The initial data collected were used as the criterion on the development of the tool.

Figure 5. Location of Initial Data Collection

3.1.3 Identification of Parameter and Data Cleaning

The LiDAR data collected were subjected to cleaning to ensure the quality and eliminate outliers. In order to have a basis in the cleaning of the data, identification of the parameters was done first. The initial data gathered were graphed or plotted in 3D to identify the following parameters — road width, road length, and center line. Through this, boundaries were set and the quality of data that was analyzed by the program was improved.

3.2 Development of the Tool

The developed tool is a Python-based software program designed to analyze and visualize road surface data collected via LiDAR. The primary function of this tool is to transform raw LiDAR output data into meaningful insights about road geometries, including the generation of 3D profiles, computation of road width, and cross slope measurements. Below is a detailed explanation of the tool's components and functionalities.

3.2.1 Data Input and Preprocessing

The tool accepts input in the form of a .txt file containing LiDAR data. This data includes parameters such as angle (θ), distance (r), and timestamp, which are critical for constructing the road profile. The data is preprocessed by converting polar coordinates (angle and distance) into Cartesian coordinates using the formulas $x = r \cdot \cos(\theta)$ and $y = r \cdot \sin(\theta)$. This transformation facilitates the visualization of the road surface in a 3D space.

3.2.2 Time-Based Positioning

To approximate the vehicle's traveled distance, the tool utilizes time-based positioning due to the LiDAR's limitation in directly measuring this distance. Timestamps recorded in the LiDAR data are formatted as YYYY-MM-DD HH:MM:SS These timestamps are converted into seconds to facilitate time-based calculations. By setting the initial timestamp as a reference (zero-time), subsequent timestamps are subtracted from this reference point to provide an estimated temporal progression of the vehicle's movement. Importantly, this time-based data is correlated with the STRAVA app, which provides GPS-based location tracking. By synchronizing the time data with STRAVA, the tool accurately determines the exact geographic location of each road segment being analyzed. This integration allows for precise mapping of the analyzed road sections, ensuring the spatial accuracy of the data and enhancing the reliability of the analysis.

3.2.3 3D Visualization and Computations

The visualization of the processed data is achieved using the Matplotlib library, where a 3D scatter plot is generated. In this plot, the x-axis represents time (in seconds), the y-axis denotes the road width, and the z-axis corresponds to the road depth. Color gradients are applied to enhance the interpretation of the data, where sections of the road with a slope less than 0.02 are colored red to indicate minimal slope variation, and areas with more significant slope differences are colored green. This visual differentiation is critical for quickly identifying areas of interest, such as potential drainage issues or slope-related safety concerns.

Road width is computed by measuring the distance between the farthest points along the y-axis in the 3D plot, reflecting the physical width of the road. Cross slope calculations are performed by determining the angle between a vector perpendicular to the calculated road width and the horizontal axis, which provides an understanding of the road's lateral slope. These calculations are crucial for evaluating road safety and surface water drainage capabilities. The program computes minimum, maximum, and average cross slopes by analyzing continuous slope measurements derived throughout the dataset. These aggregated metrics provide a comprehensive overview of the road surface profile, enabling detailed assessment of road geometry variations.

3.2.4 User Interaction

The tool is designed with a user-friendly interface to ensure accessibility. Users can run the tool by executing an .exe file and selecting the appropriate .txt file containing LiDAR data, making it suitable for use by individuals without extensive programming knowledge. This interface simplifies the process of analyzing road geometries and visualizing the results, ensuring that the tool can be effectively utilized in various operational scenarios.

3.3 Validation

The data gathered from the initial data collection was validated using the conventional way of measuring pavement properties on the same stretch of road. The cross slopes were measured for every 20 m using leveling. After calculating the cross slope using leveling and the developed tool, Wilcoxon Signed-Rank Test was used to test whether there is a significant difference between two population means. Lastly, the accuracy of the tool developed was also calculated.

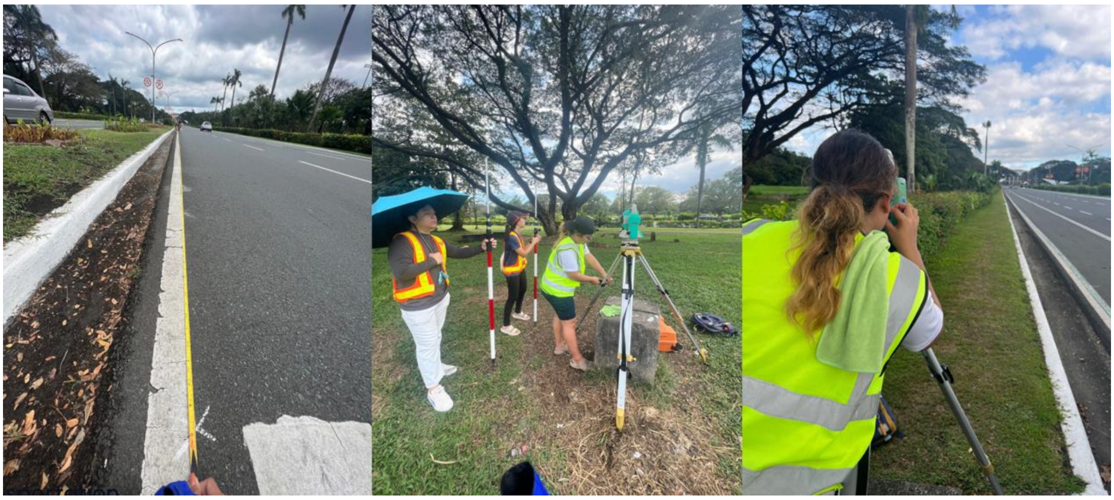


Figure 6. Cross Slope Measurement Using Leveling

3.4 Application of the Tool

The road geometric scanner and software developed were used on some road stretches outside UP for further testing and to determine the limitations of the program developed. Electronic gimbal was used to improve the stability of the LiDAR. The experiment ran on one side of the road section, without disrupting the flow of traffic, to gather LiDAR data, then the other side was done afterwards. It was ensured that the equipment configuration is stable, and not disrupted by the movement of the vehicle. In addition, the researcher used the application STRAVA throughout the duration of the data gathering to have a basis on the exact location of the road being analyzed at a specific time. Data gathered were collated by the program developed and were subjected for analysis.

3.5 Mapping

The results from the program developed were used to visualize the pavement profile and were mapped accordingly to show the compliance of selected roads to the allowable cross slope measurement. The visualized data were color coded using green; signifying sections that are still within the standard road cross slope (slopes greater than 2%), and red; signifying that the slope is below the standard range (less than 2%). By applying the color-coding method, it would be easier for the researcher to identify which road stretches are within or already below the standard cross slope range.

4. RESULTS AND DISCUSSION

4.1 Software development

Survey was conducted at the Academic Oval of the University of the Philippines Diliman, Quezon City using LiDAR mounted at the back of a vehicle together with a gimbal and a camera. The data collected was used as the criterion on the development of the tool. A user-friendly software that can evaluate the road geometry (cross slope, width, and longitudinal profile) was successfully developed and the user-interface of the software is shown below.

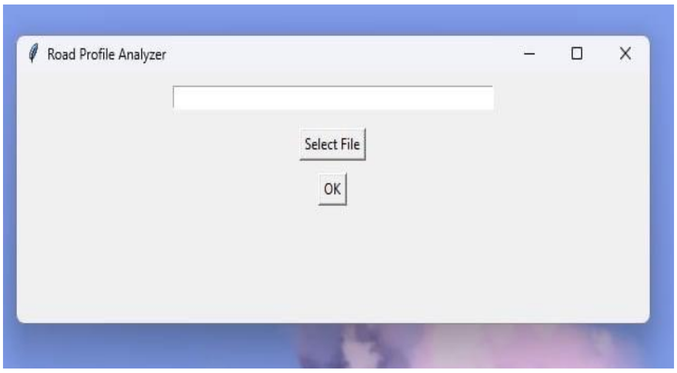


Figure 7. User Interface of the Software

The tool can create a 3D diagram visualizing the profile of the road segment. Additionally, the program can identify the maximum, minimum, and average cross slopes, as well as the road width, which are considered common road geometries. It should be noted that the width presented in Figure 8 pertains exclusively to a single lane of the road, not the entire directional road width. The 3D graph is color-coded to visualize the differences in cross slopes. The sample output of the software is shown below.

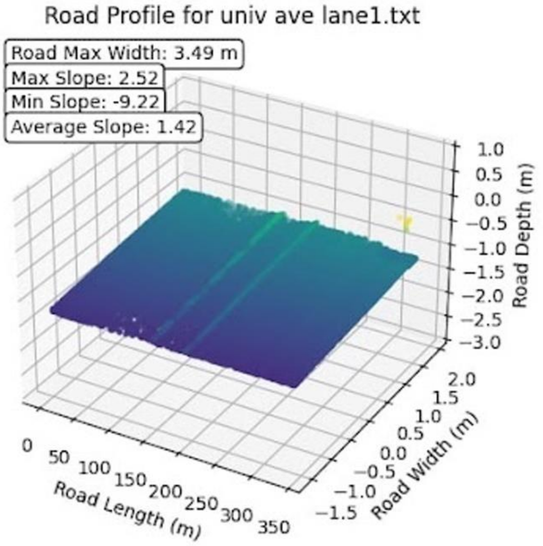


Figure 8. Road Profile of University Avenue

The tool can also graph the continuous slope of the road at a specific distance, as well as the average cross slope for every 20 meters shown in figures 9 and 10, respectively. Even though the data were already cleaned and filtered, there were still few outlier data as shown in figure 5. These outliers were balanced out by averaging the slope for every 20 meters for better interpretation of the cross slope of the road segment.

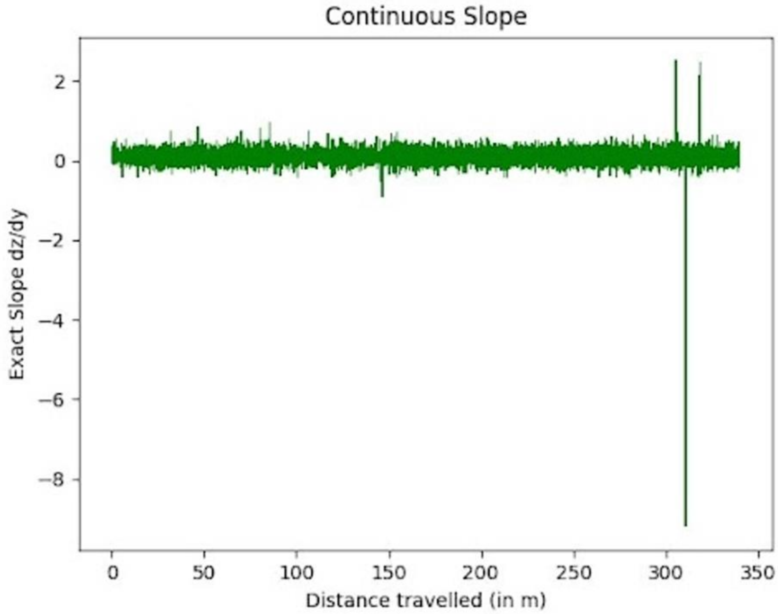


Figure 9. Continuous Slope of University Avenue

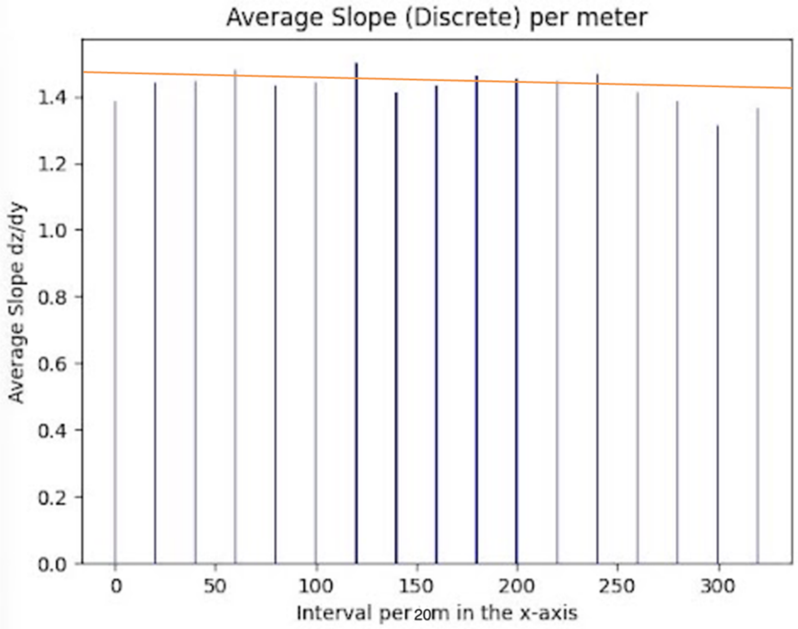


Figure 10. Average Cross Slope for Every 20m of University Avenue

4.2 Validation

	FIELD	LiDAR		FIELD	LiDAR
Sta 01	1.53754	1.43752	EAST TO WEST	1.45774	1.51720
Sta 02	1.40163	1.52248		1.39644	1.44646
Sta 03	1.41496	1.45828		1.49244	1.50516
Sta 04	1.34092	1.44841		1.33723	1.37302
Sta 05	1.39963	1.46561		1.55500	1.47154
Sta 06	1.40963	1.51310		1.61590	1.45108
Sta 07	1.31017	1.52858		1.60098	1.52141
Sta 08	1.05975	1.38319		1.13672	1.56768
Sta 09	1.34310	1.46400		1.12089	1.59555
Sta 10	1.55956	1.47535		1.53195	1.47298
Sta 11	1.98007	1.39652		1.50624	1.48842
Sta 12	1.73864	1.56598		1.21995	1.43761
Sta 13	1.70273	1.52561		1.49396	1.34696
Sta 14	1.78939	1.46471		1.56129	1.56546
Sta 15	1.91158	1.36722		1.52711	1.43039
Sta 16	1.78894	1.30827		1.70450	1.44838
Sta 17	2.35162	2.35750		1.73657	1.51962

Table 1. Measured Cross Slopes Using Two Different Methods

The accuracy of the tool developed was validated with the conventional method (leveling). Table 1 summarizes the cross slopes measured for every 20m along University Avenue using two different methods. The relationship of the measured cross slopes is also presented in Figure 11. The data from LiDAR range from 1.308 to 2.357 while the data from leveling have a wider range of 1.060 to 2.352. While there are values apart from the identity line, the two sets of data appear to form a cluster with one outlier. Most of the cross slopes fall on 1.5 %. The LiDAR data has an accuracy of 76.6 % with the Leveling data.

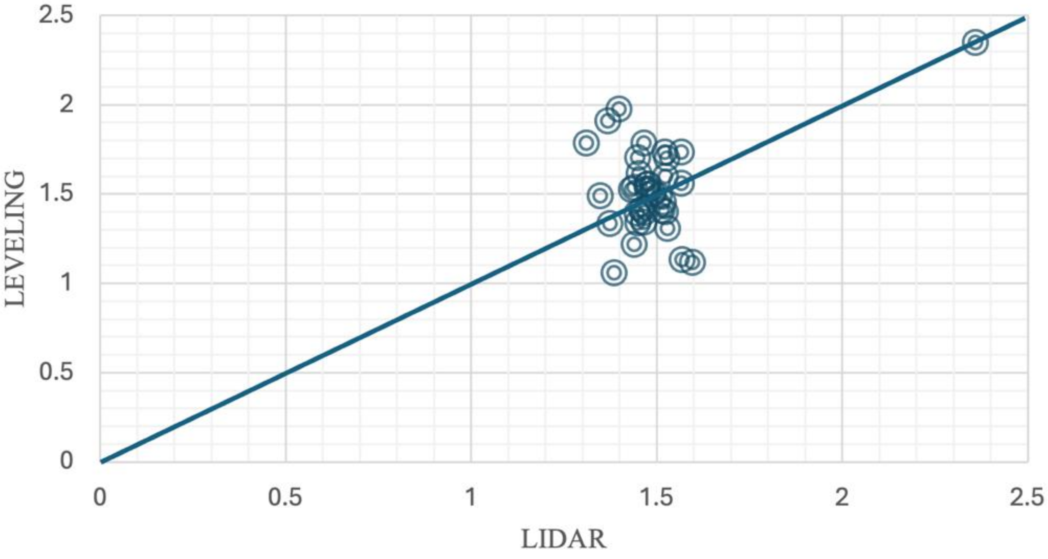


Figure 11. Relationship Between the Measured Cross Slopes Using Leveling and LiDAR

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
Field	34	1.060	2.352	1.530	0.258
Lidar	34	1.308	2.357	1.495	0.166

Wilcoxon signed-rank test / Two-tailed test: :

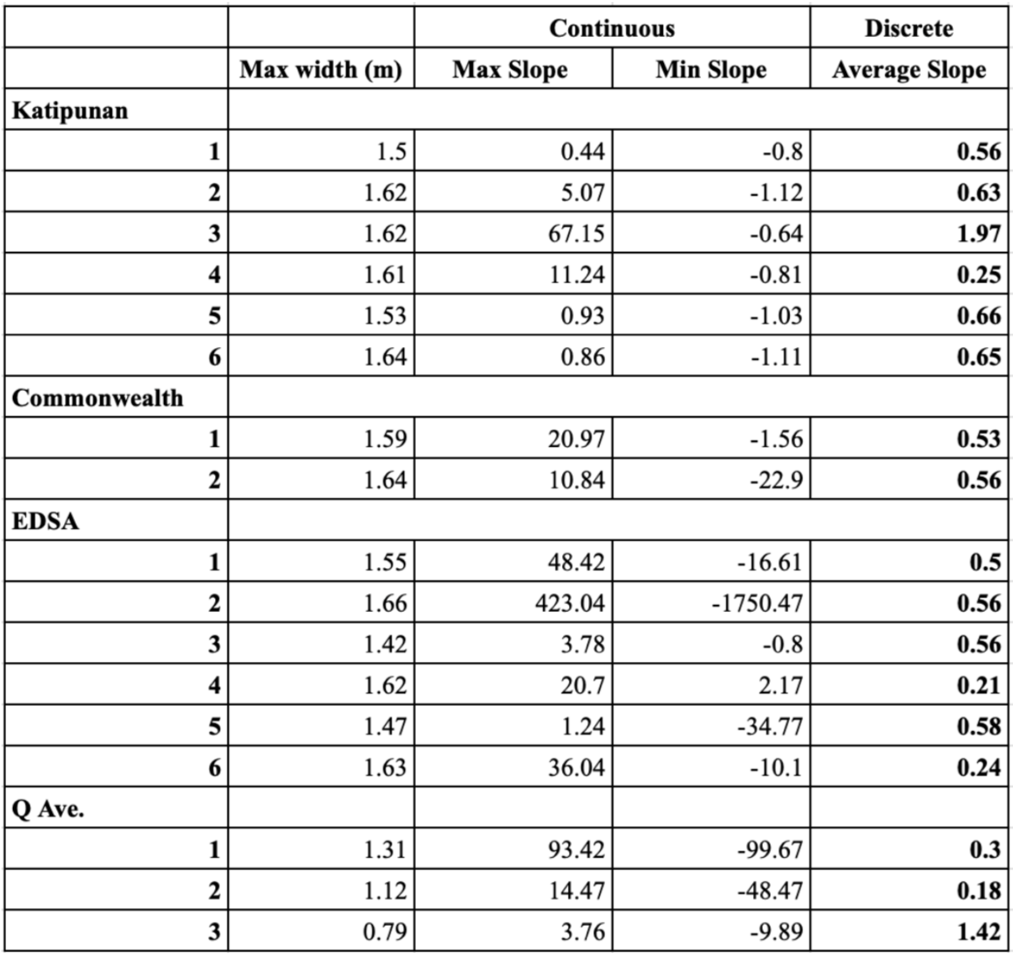
V	342
Expected value	297.500
Variance (V)	3421.250
p-value (Two-tailed)	0.457
alpha	0.05

Table 2. Summary of Wilcoxon Signed-Rank Test

After calculating the cross slope using leveling and the developed tool, a non-parametric rank test for statistical hypothesis testing, Wilcoxon Signed-Rank Test, was used to determine whether there is a significant difference between two population means. As the computed p-value of 0.457 is greater than the significance level alpha=0.05, the null hypothesis that the two samples follow the same distribution cannot be rejected. Hence, it was concluded that there is no significant difference between the two methods.

4.3 Application of the Tool

The roads that were tested are some parts of Commonwealth, C5, EDSA, Quezon Avenue, E. Rodriguez, East Avenue, Katipunan, and Ortigas Extension. The table below summarizes the details of these major roads.



		Continuous		Discrete
	Max width (m)	**Max Slope**	**Min Slope**	**Average Slope**
Katipunan				
1	1.5	0.44	-0.8	**0.56**
2	1.62	5.07	-1.12	**0.63**
3	1.62	67.15	-0.64	**1.97**
4	1.61	11.24	-0.81	**0.25**
5	1.53	0.93	-1.03	**0.66**
6	1.64	0.86	-1.11	**0.65**
Commonwealth				
1	1.59	20.97	-1.56	**0.53**
2	1.64	10.84	-22.9	**0.56**
EDSA				
1	1.55	48.42	-16.61	**0.5**
2	1.66	423.04	-1750.47	**0.56**
3	1.42	3.78	-0.8	**0.56**
4	1.62	20.7	2.17	**0.21**
5	1.47	1.24	-34.77	**0.58**
6	1.63	36.04	-10.1	**0.24**
Q Ave.				
1	1.31	93.42	-99.67	**0.3**
2	1.12	14.47	-48.47	**0.18**
3	0.79	3.76	-9.89	**1.42**

Table 2. Road Geometry of Tested Roads Outside University of the Philippines

These roads were tested using a different set up (different car and different gimbal from the initial data collection) to further analyze the limitations of the tool developed. Based on the results, there is a need for modification on the program even though it is user-friendly. It includes eliminating more outliers which are possibly but not limited to the following: obstruction from the car, vehicles from other lanes, etc. Sample raw data are shown in figure 12. It can be seen that a lot of unwanted data points were present aside from the road profile. Through the 3D graph, the user would be able to know which part of the data should be eliminated to further refine the measured cross slopes.

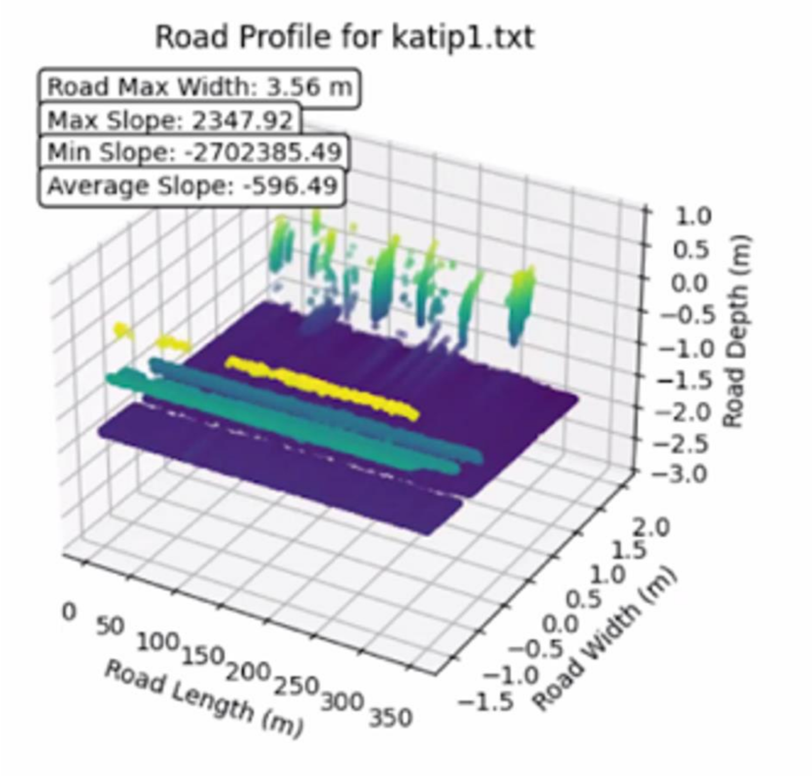


Figure 12. Sample Raw Data from Data Gathering Outside UP

4.4 Mapping

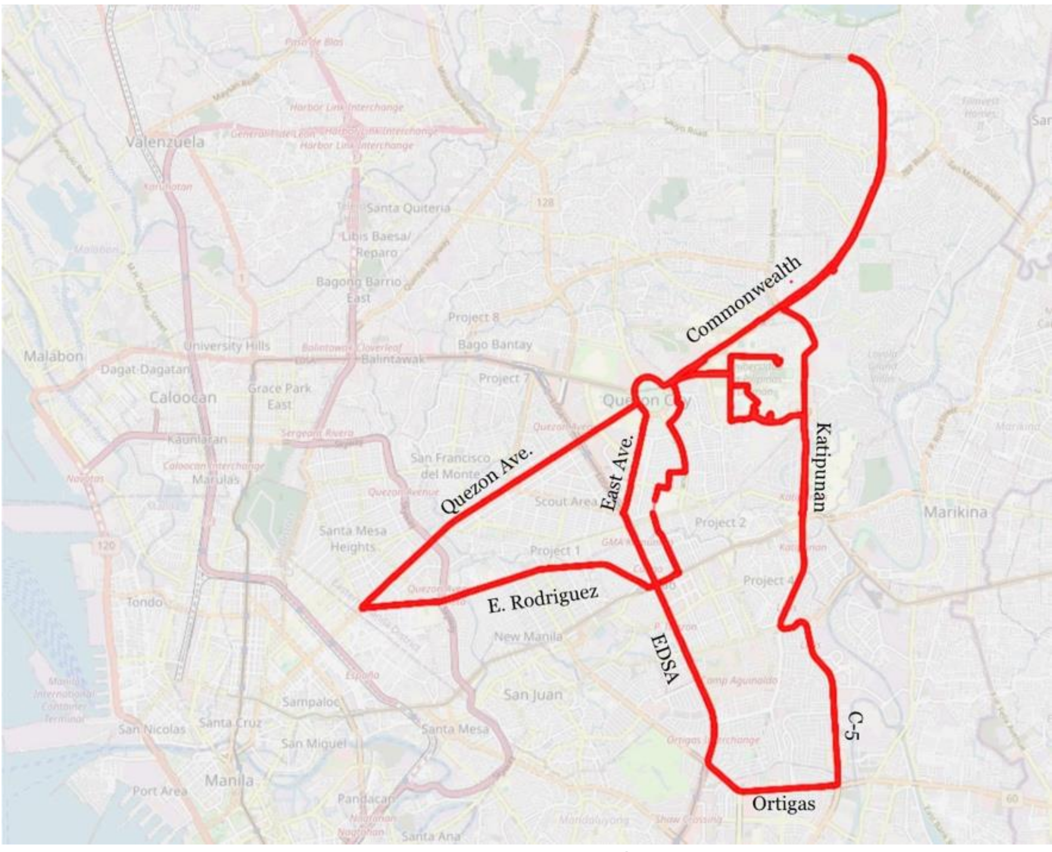


Figure 13. Visualization of the Results

Figure 13 shows visualization of the compliance of selected roads with the allowable cross slope measurement. The map is color coded using green; signifying sections that are still within the standard road cross slope (slopes greater than 2%), and red; signifying that the slope is below the standard range (less than 2%). Based on the results, it can be concluded that all of the road stretches are below the standard prescribed slope.

5. CONCLUSIONS AND RECOMMENDATIONS

Survey was conducted at the Academic Oval of the University of the Philippines Diliman, Quezon City using LiDAR mounted at the back of a vehicle together with a gimbal and a camera. The data collected were used as the criterion on the development of the tool. A program that can graph the road profile and evaluate the road geometry (cross slope, width, and longitudinal profile) was successfully developed. The tool was designed to be user-friendly since the user can easily run the .exe program and select a .txt file containing the LiDAR data.

The accuracy of the tool developed was validated with the conventional method (leveling). Wilcoxon Signed-Rank Test was used to determine whether there is a significant difference between two population means. Based on the statistical test, it was concluded that there is no significant difference between the two methods. In addition, the accuracy of the tool developed was 76.6 %.

The road geometric scanner and software developed were used on some road stretches outside UP for further testing and to determine the limitations of the program developed. The results were also mapped out to visualize the data. Based on the results, it can be concluded that all of the road stretches are below the standard prescribed slope.

It is recommended to analyze the graph of the results to further refine the measured cross slopes of the road. Since there are a lot of factors that may affect the computation of the cross slopes such as obstruction from the car and vehicles from other lanes, it would be better to modify the program relating to data clipping every analysis.

For futures studies, it is recommended to incorporate to the software developed the mapping of the results of the cross - slopes. Moreover, it is recommended to determine the correlation of the cross slope and road distresses present on roads.

Future research should expand the current software to include automated detection and analysis of pavement distresses. While the Slamtec RP Lidar A3 hardware effectively captures detailed longitudinal profiles and surface irregularities, the software is primarily optimized for cross-slope measurement. Enhancing the software to detect common pavement issues like cracks, potholes, and rutting would provide a more comprehensive road assessment and improve road maintenance and management strategies.

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